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MSc Programme in Urban Management and Development
Rotterdam, The Netherlands
September 2018

Thesis
Title: Analysis of urban Ecosystem Services supply and demand in Taunggyi, Myanmar

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Specialization: Urban Environment, Sustainability and Climate Change

UMD 14

MASTER'S PROGRAMME IN URBAN MANAGEMENT AND DEVELOPMENT

(October 2017 – September 2018)

Analysis of urban Ecosystem Services supply and demand in Taunggyi, Myanmar

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UMD 14 Report number:

Rotterdam, September 2018

Summary

This thesis aims to analyse and understand the Ecosystem Services (ES) flow between the main urban and peri-urban green spaces (UGS) and the sociological system through a Supply-Demand perspective in Taunggyi, a medium-sized city in Myanmar, in order to assess potential mismatches and provide valuable information to support future urban planning and management.

To this end, three questions were posed: (1) Which are the main green spaces in Taunggyi and how is the ES Supply distributed in the city? (2) Which are the main Ecosystem Services demanded in Taunggyi and how is the ES Demand distributed in the city? (3) How is the Ecosystem Services supply-demand balance distributed in Taunggyi and which factors might influence it?

In this study, ES supply indicators aim to estimate the flow of an ES actually used or delivered, while demand indicators measure the level required or desired by the population. The research method was a case study, which employed a mixed method approach with both qualitative and quantitative data from primary and secondary sources, depending on the type of ES analysed: GIS base maps, satellital images, national and international databases, literature references, questionnaires and open-ended questions to local experts and ward representatives, and direct site observations.

The methodological approach includes the following steps: (1) Quantification and mapping ES supply per UGS, (2) Quantification and mapping of ES supply per ward, (3) Quantification and mapping of ES demand per ward, (4) Analysis of the spatial distribution of ES supply and demand, (5) Identification of ES relationships (correlations and bundles), (5) Statistical analysis of potential influencing factors.

Hence, information was mapped and analysed using GIS and SPSS software, focusing on five specific ES relevant for the context of Taunggyi: Water provision, Urban temperature regulation, Global climate regulation, Recreation and Education.

Results from the analysis showed a clear mismatch in the ES distribution throughout the city from the Supply-Demand perspective, since the most populated (hence most demanding) areas in the centre lack any relevant ES supply while the forested areas in the peri-urban fringe provide several ES although the demand is much lower. In the case of provisioning and regulating ES this seems to be primarily related to the lack of UGS areas in the most centric wards, and in the case of cultural ES it appears to be also linked to inadequate infrastructure and management in existing UGS.

Therefore, this research suggests that certain UGS should be protected and others submit to an adaptation and management plan regarding the actual and future needs as well as the proposals stated by local residents. Moreover, it is essential to develop a strategy for the measurement, control and management of water resources in the area in order to ensure future water security, and to extend town planning scope beyond municipal boundaries including in peri-urban areas.

The assessment and mapping of ES supply-demand balance in urban areas can serve as a valuable tool to guide city planning and resource management, so it would be convenient to perform cross-city comparative research with other middle-sized cities in Myanmar in order to get more generalizable results that could be useful for UGS management and urban/regional planning in similar contexts.

Keywords

Urban Ecosystem Services, Green Infrastructure, ES Assessment, ES Mapping, GIS, Water provision, Urban temperature regulation, Global climate regulation, Recreation, Education.

Acknowledgements

I would like to first express my gratitude to my thesis supervisors Stelios Grafakos and Alexandra Tsatsou for all their encouragement and guidance during these months, for giving me the opportunity and resources to focus my investigation in Myanmar and for helping me framing and advancing through every stage of this research with their clear, instructive and valuable observations.

I am also immensely thankful to all the people who disinterestedly helped in my primary data collection in Myanmar: Nang Lawn Noung Noung and Aye Kokyaw from the Ministry of Construction in Naypyidaw; Thiri May, Aye Aye Moe and Saihtaug Kham from the Department of Urban and Housing Development in Taunggyi; my enthusiast translator Khun Thein Hun; my guide and friend Khun Kyi Lay form the ERA volunteering group, and all the officers and ward representatives who kindly participated in the local data collection.

To all the IHS academic staff for the inspiration and knowledge shared during this year and for creating, together with my fellow UMD14 students, a wonderful stimulating atmosphere to learn and grow from experiences and viewpoints from all over the world.

Finally, to my family for their unconditional support; and to the friends I made which became my Dutch family this year.

Abbreviations

CICES	Common International Classification of Ecosystem Services
ES	Ecosystem services
FAO	Food and Agriculture Organisation
GI	Green Infrastructure
GIS	Geographic information system
IPBES	Intergovernmental Panel on Biodiversity and Ecosystem Services
MCCA	Myanmar Climate Change Alliance
MAES	Mapping and Assessment of Ecosystems and their Services
MEA	Millenium Ecosystem Assessment
NbS	Nature-based solutions
UGS	Urban Green Spaces
UN	United Nations
UHI	Urban Heat Island
TEEB	The Economics of Ecosystems and Biodiversity
NGO	Non Governmental Organisation
UNDP	United Nations Development Programme

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Chapter 1: Introduction

1.1 Background

Improving liveability in cities and effectively adapting them to the impact of climate change is one of the biggest challenges that humanity is facing today. On the one hand, more than half of the global population lives in cities (United Nations. Department of Economic and Social Affairs 2017), and almost all population growth in the 2010–2050 period is expected to occur in urban areas, with the highest population growth rates attributed to African and Asian Countries (United Nations. Department of Economic and Social Affairs 2017). On the other hand, historically most cities were situated in strategic locations near the sea coast or rivers to enhance trade and economic prosperity, with the inconvenience that these sites are also at greater risk from climate hazards such as cyclones, high winds, flooding or coastal erosion. This global urbanization process scenario, together with the projected increase in the severity and periodicity of extreme events due to climate change, result in an unprecedented challenge to design strategies to make cities more adaptable and resilient to climate hazards.

Although traditionally research and political attention had focused on the world's megacities as hotspots of risk from climate hazards, in the last years small and mid-sized cities' (300,000 up to 5 million inhabitants) importance is gaining recognition, as they are expected to experience the fastest population growth rate. Additionally, they usually have poor quality infrastructure and governance systems, and budgetary constraints and lack of data on hazard-prone urban areas make it difficult to invest and implement solutions for climate resilience (Birkmann et al. 2016). However, they have a great potential to achieve urban resilience to climate change as they tend to be easier to manage than megacities, and strategies implemented now can expand as cities grow (Birkmann et al. 2016). Hence, even the United Nations' New Urban Agenda, adopted in October 2016, claimed that "strengthening the role of small and intermediate cities" was vital for urban planning and management (UN. Habitat 2016).

Urban expansion in Asia, the most populous continent in the world with a total population of 4.5 billion (United Nations. Department of Economic and Social Affairs 2017), was characterized by rapid population and economic growth rates for the last decades, which at the same time caused multiple urban environmental challenges, as a significant increase in resource footprints, air and water pollution, waste generation, CO2 emissions, or loss of arable land (UN-Habitat and UNESCAP 2015). Despite the fact that population growth rates are globally decreasing in Asia since the 1990s, most of East Asia's population is still non-urban and demographic forecasts estimate that for the decades ahead Asia's population will continue growing (United Nations. Department of Economic and Social Affairs 2017).

This is the case of Myanmar, which showed a low urbanization level and economic growth in the past decades, partly caused by the political and economic isolation of the military dictatorship that controlled the country from 1962 to 2011. However, Myanmar's economy has a significant potential to catch up with the dynamics of other countries in South-East Asia, thanks to its variety of natural resources, rich and diversified agricultural base and open access to sea. While the rural population is still predominant with the 70.4% of the population, a long-term shift from agricultural production to manufacturing is expected to increase the urban population share to 50 per cent by 2040 (MCCA/UN-Habitat 2017a).

As stated by the technical report for risk assessment published by WWF, MCCA and UNHabitat, both rapid development and climate change will add more risks to already fragile ecosystems, livelihoods, infrastructure and economic growth in Myanmar, so it is vital to implement flexible adaptation programs at the local level (Horton et al. 2017). Indeed, national reports highlight the importance of promoting natural resource management and enhancing the resilience of biodiversity and ecosystem services through ecosystem-based adaptation, capacity-building and awareness-raising initiatives to support social and economic development (MCCA/UN-Habitat 2017b).

In this regard, one of the approaches that has gained increasing attention in the last decades by both policy-makers and researchers are "Nature-based Solutions" (NbS) or "soft" adaptive measures (Sovacool 2011), as opposed to traditional hard-engineering interventions that are often expensive, complex and inflexible, and might even generate negative and unforeseen impacts on surrounding human and natural systems (Jones et al. 2012). Nature, in contrast, is inherently plastic and there is increasing evidence that "can provide flexible, cost- effective and broadly applicable alternatives to cope with the magnitude, speed and uncertainty of climate change" (Munang, Thiaw, Alverson, Mumba, et al. 2013). Moreover, natural approaches provide multiple benefits to society and the environment, including disaster risk reduction, livelihood sustenance and food security, biodiversity conservation, carbon sequestration, and sustainable water management (Colls et al. 2009). Thus, it addresses many of the concerns and priorities identified by the most vulnerable countries and people.

Consequently, numerous initiatives in policy agendas and environmental research advocate for the use of nature to address societies' challenges, providing at the same time human well-being and biodiversity benefits. At the urban scale this can be delivered by the concept of Green Infrastructure (GI), defined by the EC as a "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ES. It incorporates green spaces and other physical features in terrestrial and marine areas" (The European Commission 2014, p.3).

Ecosystem Services (ES) refer to "the direct and indirect contributions of ecosystems to human well-being" (TEEB 2010), and are commonly classified in four broad categories: provisioning, regulating, cultural and supporting or habitat services. Thus, broadly speaking, it can be said that the ES framework aims to study the interaction between ecosystems and human well-being, and GI and NbS are concepts that help operationalize it (Pauleit et al. 2017).

Hence, urban ES assessments are an essential tool to evaluate and measure the capacity of urban green spaces (UGS) to enhance environmental quality, climate resilience and human well-being in cities. Particularly when they are expressed in a spatially explicit format, ES assessment has proven to be really useful to inform policy makers and institutions in order to further implement GI into local town planning (Daily and Matson 2008; Maes et al. 2016).

Despite the aforementioned importance of cities as focal points of climatic and environmental risk, up to now most ES research has focused in the regional or national scale, with only a few of them referring to urban ES (Gómez-Baggethun and Barton 2013). Moreover, previous literature has pointed out an important knowledge gap related to urbanization and ES research, which is the little attention paid to the demand of ES (needs, preferences and policy targets) compared to the studies over the provision or supply of ES, and the evaluation of whether that demand matches or not the capacity of urban ecosystems to deliver ES (Haase et al. 2014; Wolff et al. 2015; Burkhard et al. 2012).

As such, this thesis aims to explore this gap by measuring the extent to which the ES supply actually delivered by UGS meet the current demand in a mid-sized city in Myanmar, and analyse their distribution and potential bundles along the different wards of the city.

1.2 Problem Statement

Taunggyi, the capital and largest city of the Shan State in Myanmar, is regularly affected by natural hazards as flooding, landslides and water scarcity, which are expected to increase due to the effects of climate change together with the urbanization process that is reducing the vegetation cover at the urban scale, and the deforestation happening at the regional scale.

Despite the favourable economic development for the last decades in Taunggyi, rapid urban growth in the recent years produced a dense urban environment vulnerable to climatological effects, and lack of climate-adaptive infrastructure and planning could further worsen the current trend. However, the promotion of sustainable development and climate adaptation policies can counteract these effects, especially in this kind of medium-sized cities that can still reorient their development strategy if they are provided with adequate information and tools.

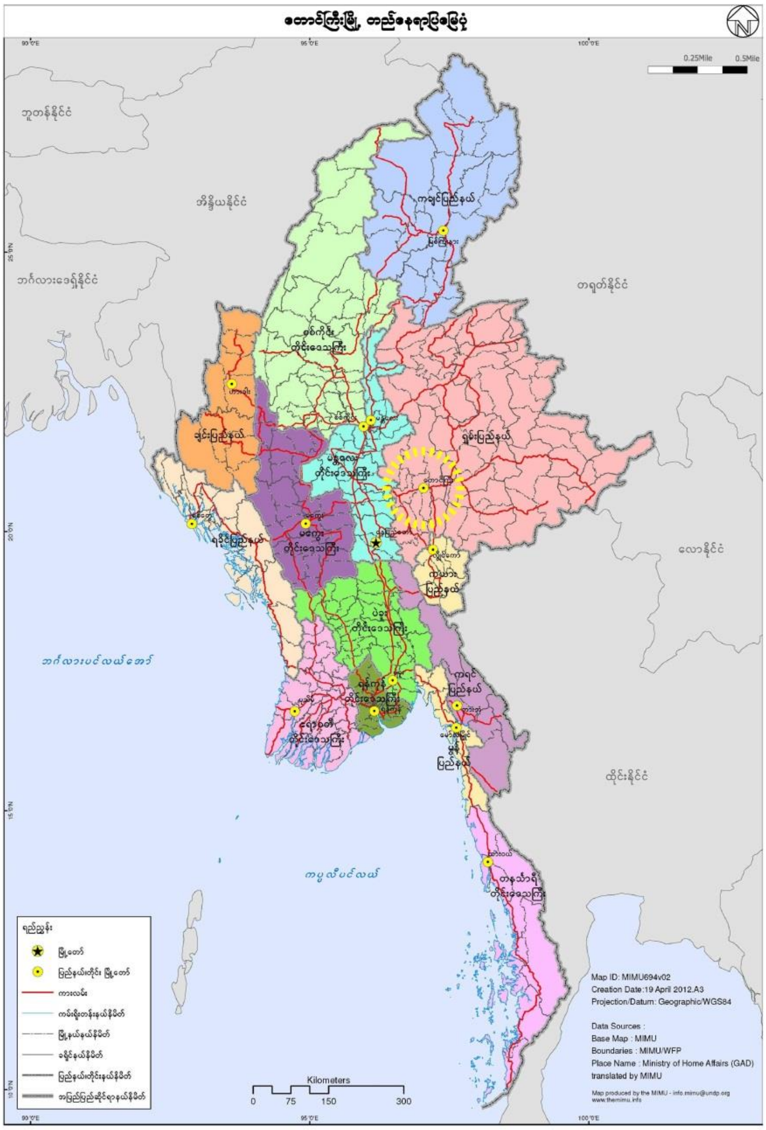

Figure 1: Taunggyi city location map.

Source: Myanmar Information Management Unit, 2012.

An approach that has proven to be successful in enhancing urban climate resilience and human well-being is working with urban green spaces (UGS) as a Green Infrastructure network adequately managed to deliver different Ecosystem Services (ES). Hence, the study of the urban ES, particularly analysing the extent to which the supply from urban green spaces (UGS) meets the actual demand for certain social and environmental quality conditions in the city, can act as a first step in this direction.

The local government is developing a new Town Development Plan for Taunggyi, which recognizes urban and peri-urban ecosystems as important features for the resilience of the city. However, they did not deliver a quantified ES assessment of those UGS and at the moment the local government lacks the information, tools and human resources necessary to carry out these kind of studies.

This thesis, therefore, will be a first approach to address the unexplored field of examining whether the benefits delivered by UGS in terms of risk reduction, water provision and cultural services supply meet the existing demand for ES by the local population in Taunggyi.

1.3 Research Objective

The aim of this research is to identify, map and evaluate ES in Taunggyi from a supply-demand perspective in order to understand the ES flow between the main urban and peri-urban green spaces (UGS) and the sociological system, thus providing information to support future urban planning and management.

For this purpose, the specific objectives of the study are the following:

- Identify, analyse and map the Ecosystem Services supplied by the main UGS in Taunggyi.
- Identify, analyse and map the Ecosystem Services (ES) demand in Taunggyi.
- Analyse the balance between supply and demand in Taunggyi, ES associations and potential factors that might influence them.

1.4 Provisional research question(s)

Main research question:

To what extent do the Ecosystem Services supplied by urban green spaces meet the Ecosystem Services demand in Taunggyi, Myanmar?

Specific research questions:

a) Which are the main green spaces in Taunggyi and which Ecosystem Services do they provide?
b) Which are the main Ecosystem Services demanded in Taunggyi?
c) How is the Ecosystem Services supply-demand balance distributed in Taunggyi and which factors might influence it?

1.5 Significance of the study

Policy relevance

Many scholars have recognized the strategic importance of Ecosystem Services assessment for climate change adaptation and disaster risk reduction (Munang, Thiaw, Alverson, Liu, et al. 2013; Demuzere et al. 2014). Developing countries are the ones that will suffer most from the effects of climate change, and yet today most studies of Ecosystem Services, especially those focused in the urban scale, have been produced and focused in Europe, North America and China (Thomas Elmqvist et al. 2013; Haase et al. 2014). Therefore, it is vital that the efforts are oriented towards the support of sustainable development and climate adaptation policies in these countries, especially in medium-sized cities that can still reorient their development strategy if they have the right information and tools.

National programs for Climate Change Strategy in Myanmar recognize the importance of conserving and enhancing ecosystems, but most cities have not developed an Ecosystem Services assessment yet. This research will contribute to fill this gap by producing spatially explicit documents about the extent to which the Ecosystem Services supply meets the demand of the population, which could support the local government and guide future policies to improve the management of green spaces in Taunggyi and other mid-sized cities in Myanmar.

Furthermore, the inclusion of participatory processes to involve the perspective of local vulnerable communities is considered vital for ES assessment and land management decision-making (Cowling et al. 2008; Koschke et al. 2012) especially in local and data scarce settings (Buytaert et al. 2014), yet it is a barely explored field in the background of Myanmar. Thus, stakeholder involvement in the assessment of context-specific ES, as cultural services among others, could be considered a rather innovative approach in Myanmar that will provide a more refined evaluation of certain ES that would hardly be reached by means of purely secondary data (Brown and Fagerholm 2015; García-Nieto et al. 2015).

Scientific relevance

Up to date, most studies on Ecosystem Services and the relationships among them (also known as ES bundles) have focused on the supply side, as there is still no clear methodological framework to quantify and map ES demand (Wolff et al. 2015). Moreover, most ES demand analyses focused on identifying the intervening socio-cultural values (Martín-López et al. 2012), and just a few produced spatially explicit results.

Besides, most ES supply-demand approaches have developed studies at the regional scale, but applying this methodology in the urban context can be particularly relevant given the high population density in cities (and therefore high number of beneficiaries), as well as the possibility of managing the pressure exerted on urban green areas (Gómez-Baggethun and Barton 2013; TEEB 2011). Therefore this thesis, although not being exhaustive, constitutes one of the first attempts to assess and spatially map ES bundles from a supply-demand approach in an urban context of a low income country.

1.6 Scope and limitations

This research will focus on the assessment of the most relevant Ecosystem Services supplied and demanded in the urban and peri-urban context of Taunggyi, Myanmar. Limitations on time, budget and data availability lead to reducing the number of services analysed to the following five: Water provision, Urban temperature regulation, Global climate regulation, Recreation and Education.

Besides, it will not be possible to study each of the existing ecosystems in the city, so a selection of the most significant ones will be made, that is, those urban and peri-urban green spaces whose area is equal to or greater than 0.5 hectare, and excluding those exclusively used for agricultural activities.

Language will be another important barrier, as respondents do not speak English and some official documents are written in Burmese language, with the consequent translation difficulties and possible misunderstandings. To overcome them, a local translator will help for the primary data collection, and municipal bilingual officers will be consulted in case clarifications are needed.

On the other hand, about the Ecosystem Services assessment itself, the lack of globally accepted measurement parameters for some of them, and the subjective character of cultural services, could imply some uncertainty to the validity of the results. In this case, the indicators will be chosen depending on the available data and following the methodology observed in the revised literature on similar case studies with a supply/demand approach.

Finally, this research should be understood as a preliminary step since it focuses on the evaluation of the current status of the ES flow from the ecosystems to the socioeconomic system; for a detailed analysis of the potential effect of specific policies or environmental changes over the current situation, the correspondent future simulations or scenario building should be conducted.

Chapter 2: Literature Review / Theory

2.1 Introduction

In this chapter, significant published literature and existing theories will be presented in order to support this research and clarify the main concepts underlying it, starting with the Ecosystem Services concept followed by their assessment methodologies, mapping techniques and tools, opportunities for stakeholder participation. Then specific characteristics of urban Ecosystem Services will be mentioned, as well as the strengths and limitations of the Ecosystem Services approach. Finally the conceptual framework on which this thesis is based will be presented.

The reviewed documentation will serve as a theoretical basis to back up this research and meet the general objective of this thesis.

2.2 Ecosystem Services

2.2.1. Ecosystem Services: Concept

As was stated in the previous chapter, one of the most broadly accepted definitions of Ecosystem Services is “the functions and products of ecosystems that benefit humans, or yield welfare to society” (M.E.A. 2005). Although this broad definition may lead to some ambiguity, it also promotes transdisciplinary research (Boerema et al. 2017).

From the time when the concept was mentioned for the first time (Schumacher, 1973), the concept of Ecosystem Services has become widely recognized by academics, policy-makers and practitioners (Seppelt et al. 2011; Notte et al. 2017). The publication of the Millennium Ecosystem Assessment ” (M.E.A. 2005) and the formation of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) were important milestone in this field.

Today, we understand ES as “the functions and products of ecosystems that benefit humans, or yield welfare to society”, through a theoretical framework that “places human well-being as the central focus for assessment while recognizing that biodiversity and ecosystems also have intrinsic value and that people take decisions concerning ecosystems based on considerations of both well-being and intrinsic value” (M.E.A. 2005). Although such a broad definition could lead to some ambiguity, some authors argue that it also promotes transdisciplinary research (Boerema et al. 2017). In brief, this approach highlights that human well-being is fully dependent on ecosystems, and that such linkages can be tracked and framed through the notion of ES.

In 2010 the cascade framework was proposed (Haines-Young and Potschin 2010), breaking the ES concept into measurable entities considering a “production chain” that links biophysical structures and processes to the benefits and values of the services provided by an ecosystem. It also contemplates the fact that feedback loops might happen, as services' values also exert pressure on ecosystems. Most ES literature has been influenced by the cascade framework (Notte et al. 2017); and two of the most widely accepted perspectives for classifying ES, The Economics of Ecosystem and Biodiversity (TEEB 2010) and CICES, the Common International Classification for Ecosystem Services (Roy Haines-Young and Potschin 2013), are based on it.

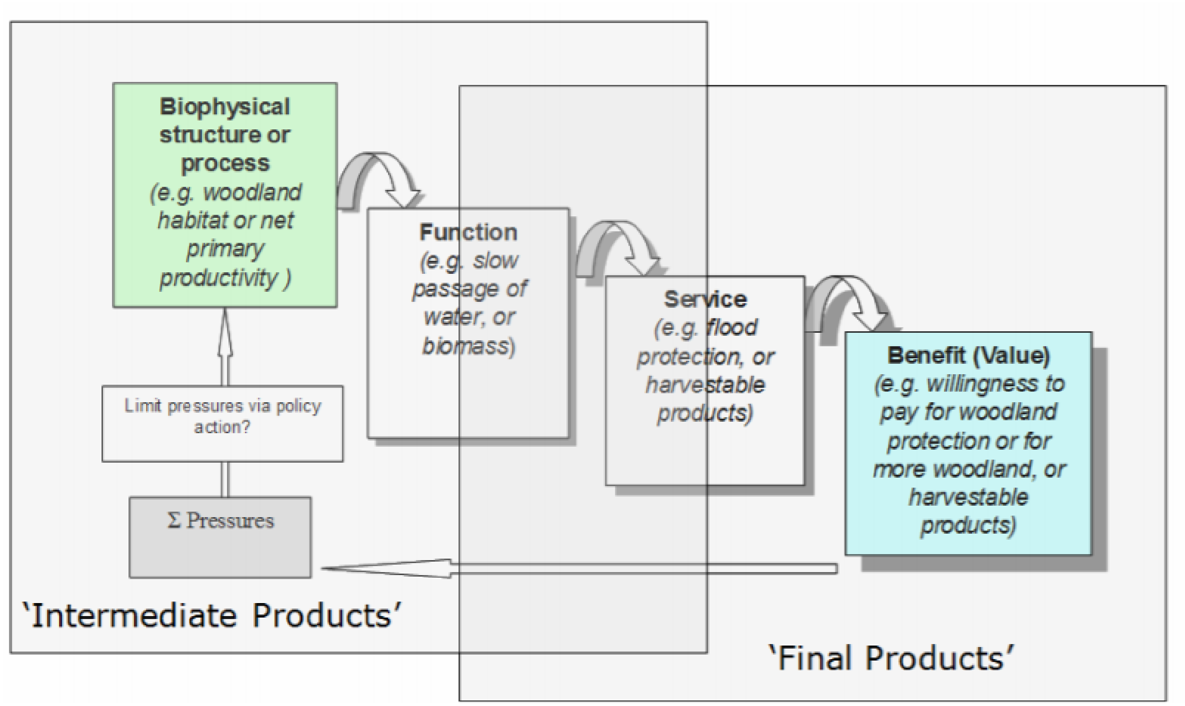

Figure 2: The ecosystem service cascade model.

Source: Haines-Young and Potschin, 2010.

This thesis will follow the categorization proposed by CICES (2018; Haines-Young and Potschin 2018), which is complementary to MEA and TEEB and aims to provide a standardization of ES for environmental accounting and valuation, following a five level hierarchical structure (section, division, group, class and class type) to define three main ES categories:

- Provisioning ES refer to all nutritional, non-nutritional material and energetic outputs from living systems as well as abiotic outputs (including water).
- Regulation & Maintenance ES include all the ways in which living organisms can mediate or moderate the ambient environment that affects human health, safety or comfort, together with abiotic equivalents
- Cultural ES cover all the non-material, and normally non-rival and non-consumptive, outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people.

Supporting ES, originally defined in the MEA, are not considered in this classification in order to avoid possible "double counting", so they are considered as part of the underlying functions that characterise ecosystems but not as final outputs.

Sec	Division	Group	Class
Provisioning	Nutrition	Biomass	Cultivated crops
			Reared animals and their outputs
			Wild plants, algae and their outputs
			Wild animals and their outputs
			Plants and algae from in-situ aquaculture
			Animals from in-situ aquaculture
		Water	Surface water for drinking
			Ground water for drinking
	Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing
			Materials from plants, algae and animals for agricultural use
			Genetic materials from all biota
		Water	Surface water for non-drinking purposes
			Ground water for non-drinking purposes
	Energy	Biomass-based energy sources	Plant-based resources
			Animal-based resources
		Mechanical energy	Animal-based energy
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants & animals
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems
			Dilution by atmosphere, freshwater and marine ecosystems
			Mediation of smell/noise/visual impacts
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates
			Buffering and attenuation of mass flows
		Liquid flows	Hydrological cycle and water flow maintenance
			Flood protection
		Gaseous / air flows	Storm protection
			Ventilation and transpiration
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance	Pollination and seed dispersal
			Maintaining nursery populations and habitats
		Pest and disease control	Pest control
			Disease control
		Soil formation and composition	Weathering processes
			Decomposition and fixing processes
		Water conditions	Chemical condition of freshwaters
			Chemical condition of salt waters
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations
			Micro and regional climate regulation
Cultural	Physical and intellectual interactions with ecosystems	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings
			Physical use of land-/seascapes in different environmental settings
		Intellectual and representative interactions	Scientific
			Educational
			Heritage, cultural
			Entertainment
			Aesthetic
	Spiritual, symbolic and other interactions with ecosystems	Spiritual and/or emblematic	Symbolic
			Sacred and/or religious
		Other cultural outputs	Existence
			Bequest

Table 1: Structure of CICES classification at the 4-digit level (Section, Division, Group and Class)

Source: Author. Adapted from (Roy Haines-Young and Potschin 2013)

2.2.2. Assessment of ES

Despite the fact that the concept of ES has been studied for decades, the approaches to their mapping and assessment are relatively recent and are still evolving (Haase et al. 2014). Currently there is not a general agreement but several different methodological approaches, indicators and units to study ES, many of them still in conceptual phase.

As TEEB recognizes, assessing the benefits received from ES is not straightforward (TEEB 2010). Instead, it is a rather complex task as several values can be related to a particular benefit, and some people might value more some benefits over others. These different values are commonly classified in three broad typologies (M.E.A. 2005; TEEB 2010):

- Ecological or biophysical values refer to the contribution of the ES to the vitality of the ecosystem, as physical or nonphysical environmental outputs with indirect value for societies (Winkler 2006; de Groot et al. 2010).
- Socio-cultural values measure the direct and indirect contributions related to socio-cultural perceptions important for human well-being, as cultural identity and heritage, spiritual values, or social relationships provided by the use or management of the ecosystems (Chan et al. 2012).
- Finally, economic values measure the direct and indirect contributions of ES to human well-being in terms of utility, and are expressed in monetary terms (Wegner and Pascual 2011; Haase et al. 2014).

Integrated assessment frameworks

International ES organisations as MEA, TEEB or IPBES as well as theoretical studies (Dendoncker et al. 2013; De Groot et al. 2002) remark the importance of integrating the social, ecological, and monetary aspects of ES holistically, in an integral manner: While monetary approaches based on market-based methods generate results that can be easily integrated into decision-making processes, sociological and ecological qualitative approaches offer the possibility of developing a comprehensive analysis including a whole range of ES (Busch et al. 2012). The selection of the appropriate assessment approach for each of the services will depend on the data availability, research objective, and the scale of the investigation of the case study.

Moreover, the integrated approach remarks that several assessment methods could (and should) be used for evaluating different dimensions of an ecosystem: for example, Pandeya et al. (2016) mention that, for the evaluation of hydrological ES it might be convenient to use a spatial analytical approach to quantify provisioning and regulating services, while the aesthetic and cultural values should be measured by a non-monetary valuation approach.

Consequently, whilst hitherto empirical literature has focused just on one dimension, commonly monetary valuation techniques (Martín-López et al. 2014; Gómez-Baggethun and Barton 2013); it is increasingly recognized that pluralistic multi-dimensional, multi-disciplinary methodological frameworks are necessary in order to capture the complexity of the systems to be analysed; and to better understand, measure and manage the dynamic relationships between humans and the ecosystems on which they rely (Martín-López et al. 2014; Carpenter et al. 2009; Barton et al. 2017).

ES Supply & Demand

Furthermore, an increasing number of scholars recognize the importance of distinguishing between ES capacity, flow and demand in ES delivery processes for a better demarcation of the service derivation from sources to beneficiaries (Villamagna et al. 2013; Burkhard et al. 2014),. This distinction builds on the previously mentioned "ES cascade model" framework by Haines-Young and Potschin (2010), which represents the links between ecosystems and human preferences along a chain of ecosystem properties, functions, services, benefits and values.

"Capacity" refers to the ES potential or hypothetical maximum yield, and "Supply" is defined as the flow or actual use of ES experienced by people (Hein et al. 2006), while "Demand" can be understood as "services currently consumed or used in a particular area over a given time period" (Burkhard et al. 2014, p.5) or as the "amount of a service required or desired by society" (Villamagna et al. 2013, p.116). Thus, the status of an ES is defined both by its provision and by the human needs (Paetzold et al. 2010; Syrbe and Walz 2012).

Linking these concepts with the three dimensions of ES valuation, the supply of an ES is commonly associated to Ecological valuation, while the demand could be measured by both Socio-cultural and Monetary methods:

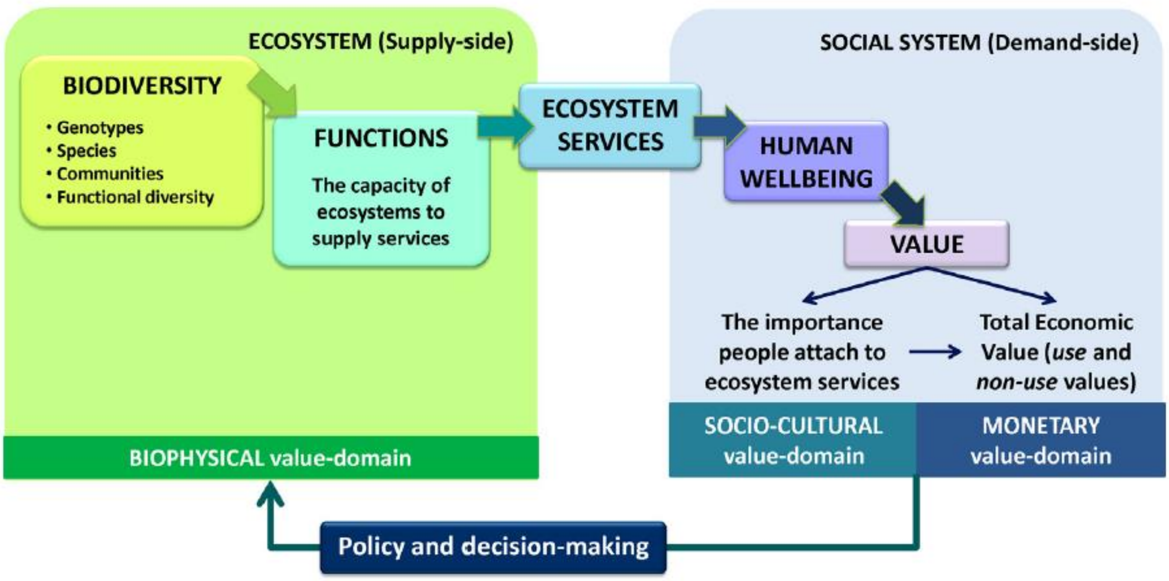

Figure 3: Methodological Framework for ES assessment based on ES Supply and Demand.

Source: Martín-López et al.,2014.

Models for quantification

Quantitative modelling is one of the principal methods for ES assessment, and the most common ones for measuring ES provision are biophysical, empirical, GIS-based and statistical models (Haase et al. 2014). Bio-physical evaluation models usually focus on provisioning services; empirical models are commonly used for analysing regulating services; and GIS-based models have proved to be more advantageous for measuring certain ES associated with landscape features as vegetation types or soil, and to map the spatial distribution of ES supply and demand. Among the monetary modelling approaches for ES valuation, the most widely used methods are cost-benefit analyses (CBA) and willingness-to-pay (WTP) analyses (Haase et al. 2014).

Regarding qualitative techniques, studies use them to analyse human behaviour and how society responds to and values ES, providing a better understanding of the associations between ecological and social dynamics in the urban or rural contexts.

ES Bundles, Synergies and Trade-offs

One of the main challenges when dealing with ES management is that they are not independent from each other (Heal et al. 2001; Pereira et al. 2005), and that they usually develop non-linear relationships (Farber et al. 2002). Regardless the growth of ES research, there is still lack of theoretical knowledge about the relationship and interactions between different ES (Tallis et al. 2008), which may lead to complications when dealing with ecosystem management and planning: if a narrow focus on a limited set of ES is used, there is a risk of unexpected losses of other ES.

These associations among ES can happen at a given location and time, or can be more generalizable to a larger extent. These ones are commonly understood as ES bundles, which are defined as “sets of ES that appear together repeatedly” (Raudsepp-Hearne et al. 2010). Associations between ES in a bundle can be positive (synergies) or negative (trade-offs), and they can be categorized in two broad typologies depending on the mechanism that produced them: in some cases a common external factor may affect several ES at the same time, and in others the supply of different ES may depend on the same ecosystem process (Bennett et al. 2009).

Analyses on ES bundles regarding the ecological (supply) and socio-economic (demand) aspects of ES relationships result in three typologies which are related to ES delivery (“supply–supply”), ES supply and demand (“supply–demand”) and among beneficiaries (“demand–demand”) (Mouchet et al. 2014).

Several studies remark that management choices tend to give preference to services that cover short-term needs of populations, as provisioning functions, even when such decisions might deteriorate ES that are vital for human well-being sustainability on the long term (Foley et al. 2005). Thus, trade-offs in regulating or cultural services, which might be less tangible and economically valuable, are usually not fully captured (Rodríguez et al. 2006).

Instead, if the processes that link ES are previously identified, and the underlying causes of the services bundles are recognized, potential trade-offs can be minimized and new synergies could be created (Bennett et al. 2009). This approach is even more fundamental in multifunctional urban regions, where dense, heterogeneous and dynamic land cover patterns make it more complex to assess and integrate ES (Haase et al. 2010).

2.2.3. Mapping ES

As many ES are geographically distributed and most policies and decisions are linked to a place based perspective, many authors have emphasized the importance of spatially explicit assessments that illustrate the relations between ES sources and benefiting populations in the territory (Crossman et al. 2013; Pandeya et al. 2016). This is specially convenient for the assessment of certain ES which are highly dependent on their spatial context like flood protection or recreational activities (Fisher et al. 2009; Andersson et al. 2015; Kremer et al. 2016). Indeed, several authors state that the generation of information relevant to local scale decision making is currently minor, so explicit mapping of ecosystem services is considered a crucial requirement for the successful implementation of the ES concept into environmental institutions and decision making processes (Daily and Matson 2008).

In the last years, different authors have developed several ES mapping approaches, although in most cases the outputs still need to be refined with more detailed spatial information and socio-economic data (Burkhard et al. 2012). Besides, there is a growing agreement on the importance of including the demand analysis into ES assessments (McDonald 2009; van Jaarsveld et al. 2005), since the status of ES is influenced as much by its provision as by the human needs and demands for the service (Paetzold et al. 2010). However, supply-demand comparison in spatially explicit representations are still rare in the academic literature (Burkhard et al. 2012).

2.2.4. Tools for ES valuation

Despite the broad recognition of the value of ecosystems for their role to enhance economic, social and environmental well-being, as the UNDP proposal of mainstreaming environment and climate to reduce poverty and achieve the Sustainable Development Goals (United Nations 2009), their actual operationalization and inclusion in policy and decision making is still residual.

In this respect, the inclusion of decision-support tools could help bridge this gap, as they can add credibility to the decision process and increase stakeholder confidence (Bagstad et al. 2013). Several tools have been developed in the last years integrating different valuation approaches and degrees of complexity, from plain spreadsheets to complex software programs. To define the research and analysis methodology of this study, different tools available at the present time were compared and evaluated.

As a first step, and regarding to the scope and limitations of this research, tools that required a payment or did not offer public use and application were dismissed. Thus, five tools were selected and a comparative analysis was carried out taking information from their developers as well as from previous academic studies (Pandeya et al. 2016; Bagstad et al. 2013; Peh et al. 2013). The result of this analysis is summarized in the table presented below:

	ARIES (Artificial Intelligence for ES)	CO$TING NATURE	InVEST	TESSA	WaterWorld
Description	Open source modelling framework to map ES flows	Policy-support tool for natural capital accounting and analysis of ES	Open source ES mapping and valuation	Toolkit for a qualitative assessment of multiple ecosystem services at a site	Tool to map water ES, build scenarios for climate change and land use change.
Software	GIS	Web based	GIS	Web based	Web based
Specific or Multiple ES	Multiple	Multiple	Multiple	Multiple	Specific (water related)
ES categories	Provisioning / Regulating / Cultural	Provisioning / Regulating / Cultural	Provisioning / Regulating / Cultural	Provisioning / Regulating / Cultural	Provisioning / Regulating
Technical knowledge	Medium	Low	High	Low	Low
Time requirement	High	Low	High	Medium	Low
Input	GIS / Databases	Provides input data but users can add their own datasets (GIS)	GIS / Tables	Mostly primary data	Provides input data but users can add their own datasets (GIS)
Output	Maps / Quantitative data / Asset portfolio	Maps / Quantitative data / Graphs	Maps / Quantitative data	Qualitative data / Guidance	Maps / Quantitative data
Max. spatial resolution	1 sq. km	1 sq. km	1 sq. km	-	1 sq. km
Scale	Local / Regional / Landscape	Local / Regional / Landscape	Local / Regional / Landscape	Site / Local	Local / Regional / Landscape
Urban Ecosystems	No	No	No	No	No
Incl. public participation	Some models	No	Some models	Yes	No
Valuation type	Biophysical / Monetary	Biophysical / Monetary	Biophysical / Monetary	Biophysical	Biophysical
Future scenarios	Yes: climate / land use change	Yes: climate / land use change	Yes, supplied by user	Yes, supplied by user	Yes: climate / land use change
Comments	Under development. Requires experienced modellers. Limited functionality for CC and LU change scenarios	It does not support mapping of individual services or estimating trade-offs	Data access limitations. Time required depends on data need and availability to support modelling	It does not provide a full quantitative valuation for ES	It does not evaluate co-benefits or trade-offs
Developer	National Science Foundation, U. of Vermont, Basque Centre for Climate Change (BC3)	Kings College London, AmbioTEK, UNEP-WCMC	Natural Capital Project	BirdLife International, U. of Cambridge, RSPB, UNEP-WCMC, Anglia Ruskin U., U. of Southampton, Tropical Biology Association	Kings College London, AmbioTEK
Website	aries.integratedmodelling.org	policysupport.org/costingnature	naturalcapitalproject.org/invest	tessa.tools	policysupport.org/waterworld

Table 2: Description of analysed ES assessment tools against key evaluative criteria.

Source: Author.

As can be observed, none of the tools is specially suited for the analysis of urban ES, and the maximum spatial resolution is 1 square km in all cases. Some of them (InVEST and Aries) are currently developing suitable models for the urban scale, but they were not publicly available by the time of this research. Hence, given the characteristics of the site under study, a middle-sized city like Taunggyi, it was decided not to employ any of the examined ES valuation tools.

2.2.5. Stakeholder involvement for ES valuation

The concept of stakeholder involvement refers to the participation of affected social groups in a decision-making process. In the ES context, Hein et al. (2006, p.213) define "stakeholder" as "any group or individual who can affect or is affected by the ecosystem's services". These can be local communities, government authorities, environmental managers, civil society organizations, private companies, etc.

Stakeholders' participation is considered crucial by many researchers in order to analyse ecosystems from the point of view of their beneficiaries, including local knowledge and societal demands in ES assessments and land management decision making (Cowling et al. 2008; Koschke et al. 2012; de Groot et al. 2010). Moreover, it is assumed to be particularly important in local and data scarce settings where conventional knowledge generation approaches might not be adequate for policy and decision making (Buytaert et al. 2014). Therefore, an increasing number of studies are based on stakeholder perceptions, either to determine the understanding and planning relevance of the concept of ES, to define an appropriate framework and select relevant ES and indicators, to collect data and develop the assessment of ES, or to evaluate different management options (Haase et al. 2014; Seppelt et al. 2011).

Several researches point out that each stakeholder group attributes **different meanings** to ES, depending on their knowledge, professional experience and socio-economic circumstances (Martín-López et al. 2012; Lamarque et al. 2011; Orenstein and Groner 2014). In this regard, participatory processes allow the inclusion of point of views from groups that have different relation and knowledge about the ecosystems, which can therefore facilitate the interaction between different groups and improve trust and shared knowledge amid them (Saarikoski et al. 2018).

Besides, power asymmetry is a concept widely used in natural resource management and social sciences, who argue that it is inherent to all social relations (Barnaud et al. 2013; Foucault 1982). Power relationships influence stakeholders' access to ES; stakeholders' interactions and roles regarding ES; and environmental management for the provision of ecosystem services (Felipe-Lucia et al. 2015). Thus, the involvement of different stakeholders' views and aspirations can **empower** them by assessing different groups' interests, roles and powers, and exposing the gap between the production of ES and the actual benefits that different groups receive (Reed et al. 2009; Felipe-Lucia et al. 2015; Fagerholm et al. 2012).

In addition, although of participatory mapping might not provide as precise geographical information as computer-aided ES mapping, it provides valuable information on the ES that local stakeholders perceive relevant for their **own well-being** (van Oort et al. 2015), which can be interpreted as a more realistic view of ES flows since the actual essence of ES is to provide benefits to society (Fagerholm et al. 2012).

Finally, public participation can improve the visibility and raise awareness of the dependence of societies on ecosystems (Klain and Chan 2012).

Consequently, participatory techniques are generally recognized as a vital perception-based information source for assessing ES and developing new policies with respect to the sustainability of ecosystems and human well-being (Hauck et al. 2013).

2.2.6. (Peri-) Urban ES

The concept and study of ES has been conventionally focused on rural and natural landscapes, rather than on urban environments; however, their recognition and understanding has been growing since the first paper on the topic arose (Bolund and Hunhammar 1999). Even though urban areas benefit from many ES provided by areas beyond their boundaries (Folke et al. 1997; Rees 1992), local ES contribute with values of vital importance as nutrient cycling, protection from heatwaves and floods, air purification, or opportunities for recreation (Gaston et al. 2013; Bolund and Hunhammar 1999; Gómez-Baggethun and Barton 2013; Haase et al. 2014).

Gómez-Baggethun and Barton (2013) state that the relevance of different urban ES varies depending on the specific and socio-economic and environmental characteristics of each site and conclude that, even though ecosystems located in urban sites are only a fraction of the total ES used in cities, the high density of beneficiaries entails a significant social and economic value of locally generated ES. Recently, Zulian et al. (2017) proposed a compilation of the key urban ES grouped according to the CICES classification:

CICES Section	CICES Class
Provisioning	Cultivated crops
	Surface water for drinking
	Ground water for drinking
	Surface water for non-drinking purposes
	Ground water for non-drinking purposes
Regulation & Maintenance	Filtration/sequestration/storage/accumulation by ecosystems
	Mediation of smell/noise/visual impacts
	Hydrological cycle and water flow maintenance
	Flood protection
	Pollination and seed dispersal
	Global climate regulation by reduction of greenhouse gas concentrations
	Micro and regional climate regulation
Cultural	Experiential use of plants, animals and land-/seascapes in different environmental settings
	Physical use of land-/seascapes in different environmental settings
	Scientific
	Educational
	Heritage, cultural
	Aesthetic

Table 3: Key urban ES organised according to the CICES classification.

Source: (Zulian et al. 2017)

Among the multiple benefits that the application of ES in the urban context, the TEEB Manual for Cities (Berghöfer et al., 2011) highlights that this approach could help visualizing the benefits derived from a functioning environment at the urban level, allowing to anticipate the consequences of potential policies, or helping with the communication of the environmental consequences and the broader economic and social implications of a decision (Mader et al., 2016).

Urban ES indicators

An indicator is information based on measured data used to represent a particular attribute, characteristic or property of a system (MEA Glossary). There is a growing interest in their use for measuring and mapping ES as a way to create solid bases for decision-making (United Nations 1992; Pintér et al. 2012; Dahl 2012), above all for regulating, supporting, and cultural services that cannot be measured straightforwardly (Feld et al. 2009; Layke et al. 2012). Indicators should be adequate for the particular service they aim to measure, comparable and simple to be easily communicated, although most frequently their selection is determined by data availability and policy objectives (Sparks et al. 2011).

There are numerous reviews for ES assessments that provide an overview on the use of indicators in this field (Feld et al. 2009; Martnez-Harms and Balvanera 2012; Crossman et al. 2013), some of them focusing in the urban scale (Dobbs et al. 2011; Maes et al. 2016). However, there is not a unified indicator framework for the assessment and mapping of urban ES, and there are still some challenges related to redundancy and their link to services and benefits (Haase et al. 2014).

One of the most widely used approaches is the MAES indicator framework for urban ecosystem services (Haase et al. 2014), which focuses on services which are relevant in cities. Recently, the European Environment Agency proposed an analytical framework for mapping and assessing ES and urban ecosystems (Maes et al. 2016), which is suitable for studies at urban, metropolitan and regional scales. This scientific framework attributes ES indicators organised according to the CICES classification, however in most cases the units for capacity and demand are not the same, which hinders making a quantifiable comparison between the levels of supply and demand in a given location. Some of the ES that could be relevant for the context of Taunggyi are reflected in the next table:

	CICES Class	Class Type	Indicator (unit)	Spatial extent		
				R	M	U
Prov.	Surface / Ground water		(Supply) Drinking water provision (m3 ha-1year-1)	o	o	
			(Demand) Drinking water consumption (m3 ha-1year-1)	o	o	o
Regulation & Maintenance	Hydrological cycle and water flow maintenance	Water flow regulation and run off mitigation	(S) Soil water storage capacity (mm)	o	o	o
			(S) Soil water infiltration capacity (cm)	o	o	o
			(S) Water retention capacity by vegetation and soil (ton km-2)	o	o	o
			(S) Intercepted rainfall (m3 year-1)	o	o	o
			(S) Surface runoff (mm)	o	o	o
	Flood protection		(S) Share of green areas in zones in danger of floods (%)		o	o
			(D) Population exposed to flood risk (% per unit area)		o	o
			(D) Areas exposed to flooding (ha)		o	o
	Global climate regulation	Climate regulation by reduction of CO2	(S) Carbon storage in soil (ton C ha-1)	o	o	
			(S) Carbon sequestration (ton ha-1 year-1)	o	o	
	Micro and regional climate regulation	Urban temperature regulation	(S) Leaf Area Index		o	o
			(S) Temperature decrease by tree cover (°C m-2)		o	o
			(S) Cooling capacity of UGI (Zardo et al.)		o	o

			(S) Cooling capacity of UGI (Derkzen et al. 2015)		o	o
			(S) Cooling capacity of UGI (Grêt-Regamey et al. 2014)		o	o
			(D) Population exposed to high temperatures (% per unit area)		o	o
Cultural	Physical use of land-/seascapes in different environmental settings	Nature-based recreation	(S) Accessibility to public parks gardens and play-grounds (between 10 ha and 50 ha) - (inhabitants within 1 km from a park)	o	o	o
			(S) Accessibility to public parks gardens and play-grounds (between 2.5 ha and 10 ha) - (inhabitants within 500 m from a park)		o	o
			(S) Accessibility to public parks gardens and play-ground (between 0.75 ha and 2.5 ha or smaller) - (inhabitants within 250 m from a park).			o
			(S) Weighted recreation opportunities provided by Urban Green Infrastructure (Derkzen et al. 2015)			o
			(S) Nature based recreation opportunities (includes Natura 2000; includes bathing water quality) (dimensionless) (Zulian et al. 2013)	o	o	
			(S) Proximity of green infrastructure to green travel routes (km)	o	o	o
			(D) Green related social service provided to population (dimensionless) (Secco and Zulian 2008)			o
			(S) Regression models on georeferenced data (i.e. pictures or geo tagged locations) (Tenerelli et al. 2016)	o		
	Educational	Nature-based education	(S) Accessibility of parks from schools (number of public parks and gardens within a defined distance from a school)		o	o

Table 4: Supply / Demand indicators for relevant ES delivered by urban ecosystems. R (Regional), M (Metropolitan), U (Urban).

Source: Adapted from Mapping and Assessment of Ecosystems and their Services: Urban ecosystems (Maes et al. 2016)

The MAES framework also included a set of condition or pressure indicators of urban ecosystems, covering from urban biodiversity indicators or green/built ratios to built infrastructure (population density, land use, road density) and green infrastructure indicators (urban forest pattern, tree health, GI connectivity) (Maes et al. 2016). These conditions, together with other factors pointed out by studies on social-ecological quality of UGS (as size, accessibility, security, edge configuration or flower density) are considered to impact to a significant degree their capacity of ES provision (Hunter and Luck 2015; Tian et al. 2014). Therefore, their study is vital to fully understand the causes and links between biophysical processes and the value of the services provided by UGS.

Urban or Peri-Urban?

Many researches have highlighted the importance of not considering cities as urban islands but as a process of urbanisation that gradually develops in the rural-urban continuum. Indeed, many ecological interactions extend beyond political city boundaries, so in most cases urban ecosystems comprise the hinterlands that are affected by the flow of the urban core, including city catchments, peri-urban forests and cultivated fields (Pickett et al. 2001; Gómez-Baggethun and Barton 2013).

Although there is not a unique definition of peri-urban areas, they are commonly understood as transitional zones of mixed land uses between the built-up area and its surrounding ecosystems (Douglas 2006). Providing a wide range of services from disaster risk management to water quality regulation or food security, these peri-urban forests and agricultural landscapes play a significant role in the resilience and sustainability levels of a city (Smit et al. 2001; FAO 2018b; Chen 2008). However, at the same time they are highly influenced by human activities and urban economic drivers. Consequently, poor management or degradation of these peri-urban ecosystems can lead to the loss of critical ES and increased risks, affecting all urban dwellers but most acutely poor or vulnerable populations (Marshall and al 2017).

Peri-urban green areas are especially important for compact cities which are characterized by a low capacity to provide regulating ES to their citizens due to their greenspace deficit. Indeed, this is a strong trade-off of the compact city, which for years was presented as a standard for sustainable development models by urban scholars and international organizations (Westerink et al. 2013; Russo and Cirella 2018). Today, there is a debate about how much (and what kind of) UGS are required for healthy and resilient urban environments, but latest researches indicate that innovative public policies and greening strategies, which are well connected, flexible, smart and compact in form and function increase sustainability, liveability and environmental justice (Jim 2013; Nikolaidou et al. 2016; Wolch et al. 2014).

In this respect, several authors state that if these dense and compact cities were in ecological balance with the hinterlands which provide enough natural structures, the urban core would not necessarily be hampered by a poor ES supply, but this depends on the specific ES under study and the proximity of the peri-urban green areas to the beneficiaries (Larondelle et al. 2014). Hence, there is a global trend towards addressing urban challenges at the wider level of the metropolitan scale or even the “rural-urban region”, which comprises the urban area, peri-urban areas and the rural hinterland (T. Elmqvist et al. 2013; Larondelle and Haase 2013; Piorr et al. 2011; Manes et al. 2014). In this thesis, the term “urban ES” will be used referring to the services provided by the ecosystems within the urban and main peri-urban areas of Taunggyi.

Urban ES in developing countries

The ES approach is considered an important tool to achieve climate adaptation and resilience in a city and has been extensively used in policies and scientific publications for the last decade, although there is a clear predominance of research and case studies based in North America, Europe and now China (Escobedo et al. 2018; Haase et al. 2014).

Nevertheless, there is a growing agreement on the fact that the ES approach might provide a way to integrate both urban management and environmental challenges in the developing world, as some researches have pointed at important benefits as forest belts which reduce desertification and dust storms in arid zones of Burkina Faso (Kambou, 1992); urban reforestation for biodiversity conservation and water resources preservation in Curitiba, Brazil (Cuquel et al. 2009); cooling effect by urban trees in Southwest Nigeria (Babalola et al. 2013); food provision through fruit street trees in Delhi and Kibera (Singh et al. 2010; Desgroppes and Taupin 2011); street trees for timber production in China and Malaysia (Webb 1999); or multiple sociocultural and ecologic values of Urban Forests in Colombian cities (Ordóñez and Duinker 2014).

Interestingly, the characteristics and services provided by urban green spaces have shown to be dependent on factors as the age of the urban area, species composition and historical evolution, but also the development level of a city (Strohbach and Haase 2012; Dobbs et al. 2014). Besides, the social perception and preferences of urban dwellers for some services over others vary from developing countries to the developed ones. In general, provisioning services (e.g. fruit, fuel, water or construction materials) are prioritised in lower income cities and countries, while regulating, supporting and cultural services (climate and water regulation, biodiversity conservation or recreation) receive higher values in developed cities and countries (Kendal, Martinez-Harms and Dobbs in Ferrini et al. 2017). Indeed, these changes in perceptions might also be reflected at the local scale within different income districts (Escobedo et al. 2015)

As mentioned earlier, demographic growth is concentrated in developing countries and these are the ones that are expected to suffer most from future climate related hazards, so there is an imperative need of a globally inclusive approach to study the region-specific problems that challenge low and medium-income countries (Escobedo et al. 2018).

2.2.7. Strengths and limitations of the ES approach

The Ecosystem Services approach has been the focus of many researches and policy recommendations for the past decade; however its application to real cases is not without complications. Some scholars state that ES per se are not a tool for the operationalization and management of the benefits derived from ecosystems, but a framework to showcase these services (Albert et al., 2014). Therefore, the operationalization of ES studies would need “bridging” concepts as Green Infrastructure and the development of new management policies (Pauleit et al. 2017).

Besides, as ES analyses are context-specific the methodology and results derived from this research might not be generalizable to other case studies. Moreover, the inclusion of stakeholder participation in the ES assessment, while providing essential information on residents’ perceptions for their own well-being, also adds a degree of subjectivity to the results that should be considered.

Another already mentioned limitation is the lack of complete or validated models to identify and evaluate urban ES, especially in developing countries with low data availability.

Nonetheless, the aim of this research, as a masters’ thesis, is not to provide an exhaustively detailed analysis of the ES provided and demanded in the urban context, but to present a first attempt to assess and spatially map ES bundles from a supply-demand approach that could later help guiding future urban policies and green space management in Taunggyi.

2.3 Conceptual Framework

The main concepts in the theoretical framework of this research build on the so-called "ES cascade model" (Potschin and Haines-Young 2011) and the distinction between ES capacity, flow and demand as a production chain intrinsically linking ecosystems (ES supply) and social systems (ES demand). The final objective of this thesis is to analyse the balance between ES supply and demand, expressed by the difference in the value of those variables but also by their distribution and clustering in the context of Taunggyi city.

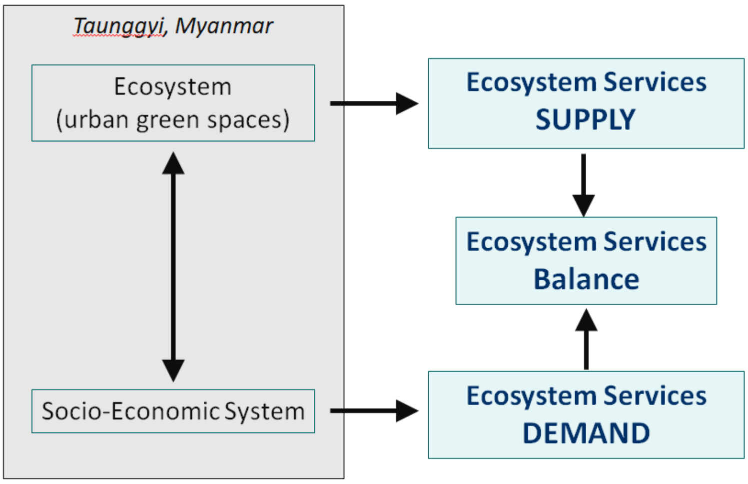

Figure 4: Conceptual Framework.

Source: Author, 2018.

Chapter 3: Research Design and Methods

This chapter will cover the transition from theoretical concepts and framework to empirical research, which is based on observable and measurable entities.

First, the research questions are reformulated so that they are in line with the conceptual framework and operationalization. Then, as a second step focused on operationalization, the concepts discussed in the previous chapters are accurately defined and translated into variables, and those variables into indicators that allow the measurement of the main concepts. Afterwards the research approach and techniques are presented, including the definition of the sampling, data collection methods, analysis instruments and techniques for ensuring research validity and reliability.

3.1 Revised research questions

To what extent do the Ecosystem Services supplied by urban green spaces meet the Ecosytem Services demand in Taunggyi, Myanmar?

a) Which are the main green spaces in Taunggyi and how is the ES Supply distributed in the city?
b) Which are the main Ecosystem Services demanded in Taunggyi and how is the ES Demand distributed in the city?
c) How is the Ecosystem Services supply-demand balance distributed in Taunggyi and which factors might influence it?

3.2 Operationalization: Variables & Indicators

The operationalization derives from the research questions and conceptual framework, concretizing a series of indicators for each of the variables so as to facilitate data collection and analysis. The five ES considered in this thesis are defined as follows:

- "Water provision": Capacity of maintaining baseline flows for water supply and discharge fostering groundwater recharge by land cover.
- "Urban temperature regulation": Regulation of local temperature by UGS, minimizing the "urban heat island" effect.
- "Global climate regulation": Carbon dioxide sequestration by terrestrial ecosystems.
- "Recreation": Nature-based opportunities for leisure activities like exercising or relaxing for mental and physical health and well-being.
- "Education": formal and informal education based on ecosystems; capacity to increase understanding of local species and ecosystems through the direct observation and experience of nature.

Ecosystem Service	Indicator	Unit	Formula	Reference	Data source
Water provision	Groundwater recharge (supply)	m^3 ha-1 year-1	Recharge = Precipitation – Interception – Evapotranspiration	Thornthwaite and Mather, 1957 USGS Soil-Water-Balance model (SWB)	Secondary & Primary: FAO climatic database (1961-2010) (FAO 2018a) USGS SWB land-use tables (USGS 2016) Google satellital images and local observation
	Water consumption (demand)	m^3 ha-1 year-1	Per capita water consumption * Ward population	National per capita water consumption	Secondary: Myanmar Ministry of Construction
Urban temperature regulation	Temperature decrease by tree cover (supply)	°C	T = Shading + Evapotranspiration	Zardo et al. (2017)	Secondary & Primary: FAO climatic database (1961-2010) (FAO 2018a) InVEST LULC biophysical tables (Natural Capital Project 2015) Ref. empirical studies for avg. temperature changes (Padmanabhamurty 1990) Google satellital images and local observation
	Temperature increase by pop. density (demand)	°C	Δ ºC per Δ pop. density	(Mallick and Rahman 2012)	Secondary: Myanmar Ministry of Construction Ref. empirical studies for avg. ºC increase (Mallick and Rahman 2012)
Global Climate regulation	Net CO_2 sequestration (supply)	t CO_2 ha-1 year-1	Tree cover area * C' C' = (C-GS) / 174	Nowak et al. (2013) Baró et al (2014)	Secondary & Primary: Nowak et al. 2013 (avg. CO_2 sequestration rate) FAO climatic database (1961-2010) (FAO 2018a) Google satellital images and local observation
	CO_2 emissions (demand)	t CO_2 ha-1 year-1	Per capita CO_2 emissions * Ward population	National per capita CO_2 emissions	Secondary: World Bank database (year 2014) (data.worldbank.org/country/myanmar) Myanmar Ministry of Construction
Recreation	Level of satisfaction with current ES supply (supply)	Preference assessment (1-5)	Average satisfaction reported by respondents; %UGS area per ward	Beichler 2015; Plieninger et al. 2013; Anthem et al. 2015	Primary data collection (questionnaires)
	ES Importance for residents' wellbeing (demand)	Preference assessment (1-5)	Average importance given by respondents	Beichler 2015; Plieninger et al. 2013; Anthem et al. 2015	Primary data collection (questionnaires)
Education	Level of satisfaction with current ES supply (supply)	Preference assessment (1-5)	Average satisfaction reported by respondents; %UGS area per ward	Beichler 2015; Plieninger et al. 2013; Anthem et al. 2015	Primary data collection (questionnaires)
	ES Importance for residents' wellbeing (demand)	Preference assessment (1-5)	Average importance given by respondents	Beichler 2015; Plieninger et al. 2013; Anthem et al. 2015	Primary data collection (questionnaires)

Table 5: Operationalization table

Source: Author, 2018.

3.3 Research Strategy

Approach and techniques

The research approach or strategy for this thesis is based on a single Case Study, as the main objective is to explore the current situation of the main UGS in Taunggyi and evaluate the ES they provide, together with their comparison with the ES demand from the population in the different areas of the city. As a relatively small number of research units have to be analysed and a deep understanding of the environmental context and societal ES demands is required to develop this kind of research (Baxter and Jack 2008), the Case Study has been chosen as the thesis strategy.

A mixed method approach with both qualitative and quantitative data from primary and secondary research methods will be applied for the analysis of the Case Study, gathering information from different sources with the aim of gaining understanding of the specific context in Taunggyi, covering various ES provided and demanded in the city and developing a holistic view of the ES flow in this urban location.

Strategy

The approach for this thesis builds on previous methodological frameworks (Mouchet et al. 2014) and consists on the following steps:

1. Selection of suitable ES indicators for both supply and demand
2. Selection and classification of the UGS in Taunggyi to study
3. Quantification and mapping ES supply per UGS
4. Quantification and mapping ES supply per ward
5. Quantification and mapping ES demand per ward
6. Analysis of the spatial distribution of ES supply and demand and their overlapping, identifying potential “greenspots” to protect and “redspots” to enhance.
7. Identification of ES relationships by analysing correlations and bundles (cluster analysis) of ES supply and demand.
8. Statistical analysis of potential influencing factors.

3.4 Sample size and selection

The area of study in this research comprises all the wards within the administrative boundaries of the city, together with some key peri-urban green areas which were added according to the information and recommendations made by local officers from Taunggyi Environmental Conservation Department (ECD) and Forestry Department. As mentioned earlier, the inclusion of peri-urban land which is highly influenced by urban drivers and which also provide urban dwellers with relevant services is essential to understand the ecological flows and interactions between ecosystems and the socioeconomic system in the context of Taunggyi.

The **selection of UGS** to include in this analysis was made according to their size and significance for the research objective, choosing public or institutional green areas of more than 0.5 hectare, both from the urban and peri-urban areas of Taunggyi, excluding other areas as private gardens and agricultural land due to time limitations.

Respecting the **spatial scale** for the analysis of the ES distribution in Taunggyi, the areas included in this study comprise all the 22 wards inside the administrative boundaries of the city as well as the three main peri-urban green areas in Taunggyi, forming a total of 25 study units.

Among the multiple benefits provided by UGS in Taunggyi, **five ES were selected** to perform the final supply-demand analysis: (1) Water provision; (2) Urban temperature regulation; (3) Global Climate regulation; (4) Recreation; and (5) Education. The ES selection was conditioned by their relevance to the context of Taunggyi, data availability, and the aim of including at least one service from each of the three ES categories proposed by CICES classification (provisioning, regulating and cultural services).

As for the **respondents** for the surveys and semi-structured interviews, they were chosen by purposive selection, as explained below:

- The selection of experts was mainly focused on socioeconomic and environmental aspects that could affect both the supply and demand of ES in the different areas of the city, so respondents were chosen from the Shan State Department of Urban and Housing Development (DUHD), City Development Committee (CDC), Environmental Conservation Department (ECD), Forestry Department in Taunggyi, as well as representatives from the environmental volunteering group from Taunggyi Technological University.
- With regard to the selection of local residents to gather information about the perceptions of the ES provided by the selected UGS as well as their demand, representatives from each of the 22 wards of the city were chosen to deliver surveys on the topic, since they had participated in previous workshops for vulnerability assessment and are well informed about the opinions and priorities of the population in each of the wards of Taunggyi.

3.5 Data collection methods

Secondary data collection

Secondary data collection was used for the assessment of provisioning and regulating ES supply and demand. Direct measurements for the different ES indicators were not available in the context of Taunggyi, so proxy indicators from national statistics or similar cases found in literature review were used instead.

Supply is mainly determined by the structure and condition of the ecosystems (de Groot et al. 2010), so the first step was to **classify the selected UGS** regarding their specific features as size, land cover, accessibility, etc. This information was gathered from the GIS database of the Municipality of Taunggyi as well as through satellital images available in Google Maps, but also local observations and indications from local experts and residents about the condition and vegetation characteristics of each plot under study. The **GIS basemaps** for all the spatial analyses were also based on the maps provided by the Municipality of Taunggyi.

Climatic information for Taunggyi was also collected to calculate supply values for Water provision, Urban temperature regulation and Global climate regulation. The main sources were the Myanmar Climate Report (Zin et al. 2017) and FAO's Digital Agricultural Atlas of the Union of Myanmar (FAO 2018a).

Secondary quantitative data was also gathered for ES demand, as the local **population density** and average per capita **water consumption** which were obtained from the Burmese Ministry of Construction; or the national per capita **carbon dioxide emissions** from the World Bank database (https://data.worldbank.org/country/myanmar), in the absence of local data from Taunggyi city.

Finally, available **empirical evidence in the literature** was also used for Urban temperature regulation supply and demand quantification (Jauregui 1990; Saito et al. 1990; Ca et al. 1998; Nowak and Heisler 2010; Mallick and Rahman 2012).

Primary data collection

Regarding to required primary data, it mainly concerned the **prioritisation of ES** in Taunggyi, as well as social perceptions' evaluation for the **assessment of cultural ES**. This information was gathered through **questionnaires and open-ended questions** to local experts and ward representatives during the fieldwork. Based on similar studies on social perception for ES assessment (Peña et al. 2015; Pan et al. 2016), all experts and ward representatives were asked to rank several ES according to their importance in the context of Taunggyi, from (1) Very unimportant, to (5) Very important.

Figure 5: Questionnaires to ward representatives during fieldwork in Taunggyi.

Source: Author.

As for the assessment of cultural ES supply and demand, a questionnaire and some open-ended questions were asked to the representatives of all the 22 wards in Taunggyi, with the assistance of a local translator and a representative from the DUHD office. The methodology is based on previous researches on cultural ES assessment (Beichler 2015; Plieninger et al. 2013; Anthem et al. 2015). First, seven potential services were selected according to their relevance for Taunggyi: Recreational value, Aesthetic value, Spiritual or emblematic value, Scientific investigation and traditional ecological knowledge, Education and training, and Community benefits.

Then, meetings with ward representatives started with an introduction and clarification of the purpose of the study. Afterwards a map of the study area (A3 format, at 1:40,000 scale) in which 40 UGS were pre-identified, numbered and classified (in the categories "Conservation", "Military areas", "Religious areas", "Sportive areas", and "General green areas") was presented to the respondents, and they were asked to indicate the ones they frequently visited, and further specify, for each of those specific UGS, and in a scale from 1 to 5:

a) The importance of each ES supply for their personal wellbeing (demand indicator)
b) The level of satisfaction with the actual ES supply (supply indicator).

They were also asked to explain the reason of their choices, registering every answer with a voice recorder. Finally, respondents were asked about their general satisfaction level with the quantity and quality of UGS in their wards. Slight modifications were made over the course of the data collection phase in order to adjust it to the local context, and supplementary UGS proposed by the participants were added.

As previously stated, direct site observation was also another primary data collection method to define the status of the various green spaces under study and to verify the information gathered by other means.

Figure 6: Aerial view of Taunggyi from one of its main green spaces, Mya Sein mountain.

Source: Author.

3.6 Data analysis methods

Three main tools were used for data analysis in this study:

- Excel spreadsheets for estimating provisioning and regulating ES values, as well as obtaining average values for cultural services from questionnaires;
- QGIS software: based on the GIS database obtained from the Municipality, the information of the correspondent ES values for UGS and wards was added to create output maps representing the spatial distribution of ES supply and demand;
- IBM SPSS software: data was exported to SPSS in order to get descriptive and inferential statistics about relations between ES indicators as well as potential factors that might influence the ES supply by UGS.

The use of GIS software in this thesis allows the spatial representation of the different ES across the city, which makes it easier to understand and communicate results than using just numbers and graphs, and allows the export of data for statistical analysis if necessary. Moreover, the spatial outputs as maps have proven to be especially adequate for supply and demand analysis (Burkhard et al. 2012), and a vital approach for their mainstreaming into institutions and decision making (Daily and Matson 2008).

3.6.1. ES Supply/Demand Quantification

For each ES, a suitable indicator was chosen for both supply and demand quantification and mapping.

In the case of **provisioning and regulating ES supply**, indicators refer to the UGS's potential capacity to provide each ES according to their specific biophysical conditions (mainly climatic and land cover characteristics), as data on local measurements for groundwater recharge, temperature regulation or carbon sequestration were not available in Taunggyi:

- The amount of Groundwater recharge for Water provisioning depends on multiple factors as rainfall, vegetation cover, soil type, subsurface geology, slope or depth of the water table. Due to lack of sufficient data for Taunggyi, a simplified model following the Soil-Water-Balance code from U.S. Geological Survey (USGS 2016) was used in this thesis using Precipitation, Interception and Evapotranspiration variables.
- Temperature decrease was estimated following the methodology by Zardo et al. (2017), which regards the effect of shading from tree cover and evapotranspiration from vegetation cover.
- Finally, Global climate regulation was calculated by the amount of CO_2 sequestered by tree cover percentage in each UGS.

Similarly, **demand for provisioning and regulating ES** was measured by the level required or desired by the population (Villamagna et al. 2013), in this case through water consumption volume, urban heat island effect due to population density, and CO_2 emissions for each ward, for which literature evidence and national per capita averages were used in the absence of more detailed information. Values were normalized by area in order to enable the comparison between the different wards in the city (see Annex B for additional calculation details).

On the other hand, **supply and demand for cultural ES** were both measured through residents' perceptions on their importance for their wellbeing and supply satisfaction level (both in a range of 1 to 5, from very low to very high). Supply scores given by the respondents were added to each UGS, to estimate a final average value for each of them, in the scale 1 to 5. Finally, all indicators initially estimated for UGS were added at ward level, using as a weighting factor the percentage of ES providing UGS area with respect to the total ward area. The methodology was similar for Demand indicators, for which the score given by respondents was weighted by the population density in each ward (see Annex B for additional calculation details).

3.6.2. ES Spatial Analysis

As a first step, values from ES quantification for each **UGS and ward** were spatially mapped as **ES supply and demand** using QGIS software, in order to visualize their **spatial distribution** over the study area.

A **spatial autocorrelation** analysis was developed out using Global Moran's I in ArcGIS software, as it was not available in QGIS. When standard deviation (z-score) was higher than 1.96, spatial clustering was considered significant.

Overlap analysis was also carried out in order to spatially visualize supply-demand balance in each ward as well as to identify ES "**greenspots" and "redspots"** in the city.

Finally, **"ES richness"** for supply and demand ES was calculated by adding the number of ES with relevant supply/demand scores (with a value equal or higher than the average) in each ward (Mouchet et al. 2014).

3.6.3. ES Statistical Analysis

With regard to statistical analysis, first **descriptive statistics** were carried out with SPSS software in order to make an overview of the components analysed in this research.

Then, associations between pairs of ES (both for supply and demand) were studied using **Pearson correlation**. This kind of analysis gives important information about which (and to what extent) ES are associated, and whether this association is positive (synergies) or negative (trade-offs),

Then, a **cluster analysis** was developed to find wards with similar ES bundle types. Wards were classified regarding the combinations of both ES supply and demand values using K-means clustering algorithm in SPSS, allows dividing ES into a predetermined number of groups (clusters) minimizing within-group variance.

3.7 Validity and reliability

Case Studies are one of the most popular strategies for applied research, where the objective is to make a contribution to solve a concrete social issue, yet commonly their results are not easily generalizable to other situations (Van Thiel 2014). Therefore, the external validity is usually low in this kind of research, while their internal validity tends to be high. Besides, because of the intensive kind of research used in Case Studies, there is commonly a high risk of subjectivity in the analysis.

To overcome these challenges, cross verification of qualitative and quantitative information from different information sources is required. In this thesis, provisioning and regulating ES supply calculation methods were taken from previous literature (Zardo et al. 2017; Nowak et al. 2013) or international organizations (USGS 2016) combined with national and international databases; however ES demand was estimated through proxy indicators in the absence of local statistical data from the Municipality of Taunggyi, but perceptions from officers and ward representatives were also used for cross-checking.

As for cultural ES, multiple researchers have based their assessment on users' perceptions, which is the methodology chosen in this study. In order to increase the validity of the information gathered from ward representatives, local officers' and experts' opinion was also collected, as well as direst site observation of the UGS included in the research.

This triangulation among different data sources and research methods helps overcoming the potential biases that could arise in this Case Study, enhancing its objectivity, validity and reliability (Golafshani 2003; Neuman 2013).

Moreover, a study protocol with a detailed description of the applied data sources, procedural steps and analysis techniques was accomplished and is explained in this thesis, in order to improve the controllability and facilitate the replication of the study by other researchers, thus boosting the general reliability of the research method (Miles and Huberman 1994; Van Thiel 2014).

3.8 Research Limitations

The research aim of covering a wide range of ES and data analysis methods in a limited timeframe, together with the factors implicit in a study of these characteristics in a developing country, entailed some limitations that should be considered in order to clarify the conditions that affected the results obtained.

First, time and budgetary constraints limited the possibility of a longer stay in Myanmar to collect information from a higher **amount of respondents**. Ward representatives and local officers and experts were the only stakeholders participating in the research, revealing a lack of group diversity in order to reflect the interests and points of view from other societal profiles. Representatives were asked to talk about their friends', neighbors' and relatives' relation to UGS, however the precision of their answers is lower than directly interviewing all different social groups.

Time constraints also restricted the **selection of UGS** to study: instead of analysing every ecosystem in the city, just the most relevant ones were assessed, avoiding the inclusion of street trees and small green areas (of less than 0.5 hectare). Several studies point out that some services as carbon storage or recreational services are specially dependent on tree density and park size, respectively (Nowak and Crane 2002; Coles and Bussey 2000), so the exclusion of single street trees and small parks might not imply highly relevant implications for the assessment of those ES. However, other kind of green infrastructure as agricultural land (quite abundant in the north and south ends of the city) was not included in this study, although it has been recognised as a key feature for city resilience and sustainability through food security and other ES, especially in developing countries.

Third, **linguistic limitations** were important, as most stakeholders in Taunggyi do not speak English. Thus, the need to use a translator for questionnaires and interviews limited the direct interaction with respondents, and their answers were analysed through the filter of the interpreter who was translating everything simultaneously. In order to ensure the correct use of technical terms related to sustainability and climate change, the translator was previously provided with an English-Burmese dictionary developed by the Myanmar Climate Change Alliance (MCCA).

Another remarkable limitation was the **lack of local statistical data** from the Municipality of Taunggyi related to biophysical aspects that were needed for delivering ES supply/demand estimations, as a Digital Elevation Model of the city to estimate water runoff; overall water consumption levels in the city (they only had consumption data about the municipal water supply network, not about underground water consumption or drinking water bought in the areas not served by the municipal system); temperature variation among different areas of the city; or carbon emissions at the city level. This fact forced the use of proxy indicators and secondary data from national databases or empirical evidence from previous studies, although some authors warn about the constraints of this methodology, especially for spatially explicit approaches (Eigenbrod et al. 2010).

Finally, the accurate analysis of **cultural values** still represents one of the greatest challenges in the ES assessment field and there are still no globally accepted measurement parameters (Milcu et al. 2013; Hernández-Morcillo et al. 2013). In this case, participatory mapping and preference assessment were used in order to estimate the supply/demand values for each cultural ES (Recreation and Education), however the subjective nature of this kind of services implies a considerable limitation in the research.

Chapter 4: Research Findings

4.1 UGS selection and categorization

The UGS that were used for this ES assessment included most green areas above 0.5 ha in the urban and peri-urban areas of Taunggyi, excluding those with agricultural uses and private gardens. They were initially classified in 5 broad categories: “Conservation”, “Military areas”, “Religious areas”, “Sportive areas”, and “General use green areas”). In order to develop an analysis based on Land Use and Land Cover characteristics of each UGS, they were further classified as follows:

Land Use typology, based on municipal land use map and primary data collection:

- Conservation area
- City park
- Neighbourhood forest
- Institutional
- Religious (green areas around pagodas and monasterys)
- Sportive
- Vacant land

Predominant Land Cover typology, based on the Land Cover Classification System (LCCS) developed by FAO (Di Gregorio, A., and Jansen 2005):

- Forest (area equal or higher than 65% UGS area)
- Shrubland (area equal or higher than 65% UGS area)
- Grassland (area equal or higher than 65% UGS area)
- Mosaic herbaceous cover (area > 60%) / tree and shrub (area < 40%)
- Mosaic tree and shrub (area > 60%) / herbaceous cover (area < 40%)
- Mosaic tree and grass (area > 60%) / shrub (area < 40%)
- Mixed vegetation with paved areas <=30% UGS area

Hence, the final selection was composed of 43 plots between 0.7 ha and 511 ha, most of them (20) corresponding to “General green areas”, 13 religious parks around temples, 5 green military areas, 3 peri-urban conservation areas (the main forest in Mya Sein mountain and two more preserved areas in the north and south of the city), and 2 sportive areas (Taunggyi football stadium and Golf Club) (Fig. 7, Table 6).

General Classific.	Code	Definition	Land Use	Land Cover	Area (ha)	Public Access	Ward(s)
Conservation	C01	Mya Sein mountain forest (East)	Conservation area	Forest	414,78	Yes	Periurban natural area 1
	C02	Preserved grassland and lakes (North)	Conservation area	Mosaic herbaceous	322,83	Yes	Periurban natural area 2
	C03	Preserved pine trees (South)	Conservation area	Forest	511,32	Yes	Periurban natural area 3
General Use	G01	Mya Kan Thar Park	City park	Forest	3,40	Yes	Nyaung Shwe Haw Kone
	G02	Bo Gyoke Aung San Park	City park	Mosaic herbaceous	0,78	Yes	Thit Taw
	G03	Park around Parliament	Institutional	Forest	4,66	Yes	Thit Taw
	G04	University green areas	Institutional	Mosaic Tree-Grass	15,58	Yes	Kyaung Gyi Su
	G05	University green areas	Institutional	Forest	7,09	Yes	Kyaung Gyi Su
	G06	Fireballoon Launching Site	City park	Grassland	10,86	Yes	Kyaung Gyi Su
	G07	Green vacant lot	Vacant	Mosaic Tree-Shrub	3,58	Yes	Kyaung Gyi Su
	G08	Green vacant lot	Vacant	Mosaic Tree-Shrub	3,68	Yes	Kyaung Gyi Su
	G09	Green vacant lot	Vacant	Forest	2,00	Yes	Kyaung Gyi Su
	G10	Neighbourhood green space	Neighbourhood forest	Forest	1,66	Yes	Kan Kyi
	G11	Neighbourhood green space & lake	Neighbourhood forest	Forest	1,56	Yes	Kan Kyi
	G12	Green vacant lot	Vacant	Shrubland	15,57	Yes	Sat Sen Htun
	G13	Green vacant lot	Vacant	Mosaic Tree-Shrub	16,11	Yes	Phayar Phyu
	G14	Green vacant lot	Vacant	Forest	6,35	Yes	Phayar Phyu
	G15	Green vacant lot	Vacant	Forest	0,74	Yes	Phayar Phyu
	G16	Neighbourhood green space	Neighbourhood forest	Forest	1,48	Yes	Phayar Phyu
	G17	City forest	Vacant	Forest	14,71	yes	Phayar Phyu
	G18	Eastern Amusement park	City park	Forest	5,60	Entrance fee	Sat Sen Htun
	G19	Green vacant lot	Vacant	Shrubland	33,62	Yes	
	G20	School park and lake	Institutional	Mosaic Tree-Grass	9,76	No	Kyaung Gyi Su
Military	M01	Military base	Institutional	Paved-Mixed veg	254,05	No	Sat Sen Htun
	M02	Green military area	Institutional	Mosaic herbaceous	146,32	No	Phayar Phyu, Periurban n. a. 2
	M03	Green military area	Institutional	Mosaic Tree-Shrub	290,16	No	Periurban natural area 1
	M04	Military base	Institutional	Paved-Mixed veg	60,01	No	Kyaung Gyi Su
	M05	Military base	Institutional	Mosaic Tree-Grass	4,64	No	Thit Taw
Religious	R01	Par Moe Nae Monastery	Religious	Forest	2,11	Yes	Phayar Phyu

	R02	Pyinnya Bawdi Monastery	Religious	Mosaic Tree-Shrub	19,49	Yes	Phayar Phyu
	R03	Kone Thar Monastery	Religious	Forest	6,95	Yes	Kan Ther, Chan Ther
	R04	Sonn Laoon Gu Monastery	Religious	Forest	10,14	Yes	Kan Ther
	R05	Minn Konn Zay Ta Wun Monastery	Religious	Paved-Mixed veg	8,47	Yes	Kyaung Gyi Su
	R06	Su Taung Pyae Monastery	Religious	Forest	4,38	Yes	Chan Ther, Kyaung Gyi Su
	R07	Standing Buddha Image Pagoda	Religious	Forest	4,54	Yes	Chan Ther
	R08	Su La Muni Pagoda	Religious	Mosaic Tree-Shrub	4,11	Yes	Thit Taw
	R09	Monastery	Religious	Paved-Mixed veg	7,16	Yes	Kyaung Gyi Su
	R10	Cemetery	Religious	Paved-Mixed veg	76,27	Yes	Kyaung Gyi Su, Out
	R11	Ngwe Taung Pagoda	Religious	Forest	8,94	Yes	Kyaung Gyi Su
	R12	Kan Gyi Monastery	Religious	Forest	2,34	Yes	Kan Kyi
	R13	Cemetery	Religious	Shrubland	1,67	Yes	Phayar Phyu
Sportive	S01	Golf Club	Sportive	Mosaic Tree-Grass	35,02	Entrance fee	Kyaung Gyi Su
	S02	Football stadium	Sportive	Grassland	3,94	Entrance fee	Thit Taw

Table 6: Classification and characteristics of selected UGS.

Source: Author.

About the **Land Use** classification, the most common use within the studied land lots was “Religious” (13 plots, 30% of the total number of UGS), followed by “Institutional” and “Vacant land” (each of them with 9 plots, 21% of the total), “City parks” (3 plots, 9%), “Conservation” and “Neighbourhood forest” (each with 3 plots, 7%), and finally the two sportive areas (5% of the total).

As for the **Land Cover** typologies, the most frequent one was “Forest” cover (20 plots, 47% of the total number of UGS), followed by “Mosaic tree – shrub” (6 plots, 14%), “Mixed vegetation with paved areas” (5 plots, 12%), “Mosaic tree – grass” (4 plots, 9%), “Shrubland” and “Grassland” (3 plots each, 7%), and finally “Mosaic herbaceous” (2 plots, 5%).

Regarding the total area of each Land Cover type, the results were the following, in descending order: “Forest” (1015 ha, 43% of the total UGS area), “Mosaic herbaceous” (470 ha, 20%), “Mixed vegetation with paved areas” (405 ha, 17%), “Mosaic tree – shrub” (337 ha, 14%), “Mosaic tree – grass” (65 ha, 3%), “Shrubland” (51 ha, 2%) and “Grassland” (15 ha, 1%).

With reference to the free **accessibility** to the studied UGS, most of them are accessible (34, the 79%) while 9 of them (21%) are not. These are the six military areas, the two sportive areas and the Eastern Amusement park which require an entrance fee.

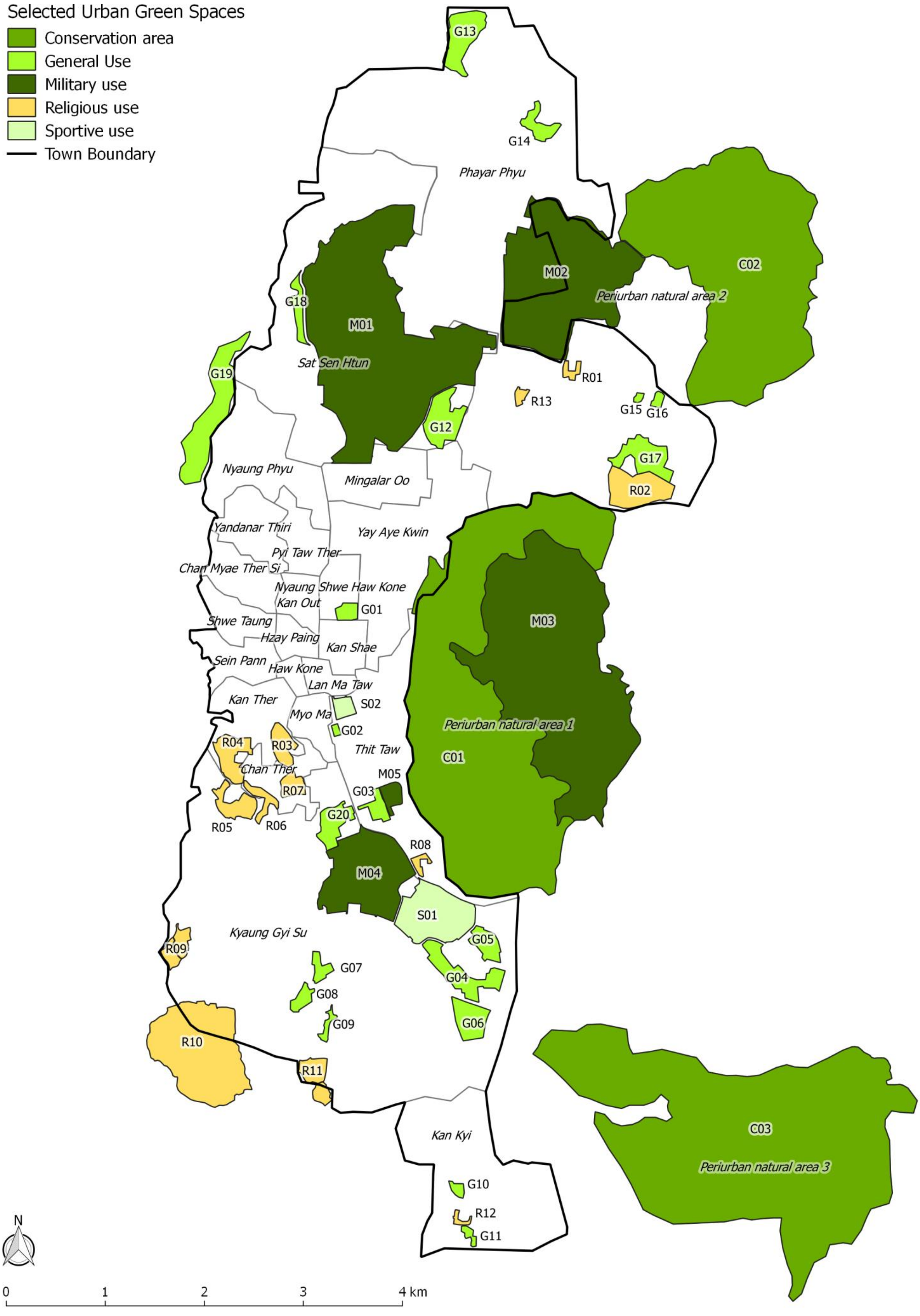

Figure 7: Spatial distribution and classification of the selected UGS in Taunggyi.

Source: Author.

4.2 ES prioritization and Cultural ES selection

As stated in the previous chapter, one of the first steps of the research was to select certain ES in order to develop the supply-demand assessment. In this regard, local experts and officers were first asked to prioritise the category of ES most relevant for the context of Taunggyi, in a rank from 1 (Very low importance) to 5 (Very high importance). In this regard, Provisioning ES earned the highest score (4.8), closely followed by Cultural ES (3.73) and Regulating ES (3.5) (see Annex A for ES categories prioritization scores).

Afterwards, the five final ES were chosen attending to their relevance for the context, data availability and the aim of including at least one service from each of the three ES categories.

For the selection of the final ES to analyse in this study, questionnaires for the assessment of cultural ES initially presented 6 services to the respondents, of which only two were finally included in the final ES Supply/Demand assessment. The initial 6 cultural ES typologies, chosen after consultation with local experts, were the following (adapted from The Economics of Ecosystem and Biodiversity (TEEB 2010)):

- “Recreation”: Nature-based opportunities for recreation like exercising or relaxing for mental and physical health and well-being.
- “Aesthetic value”: Beauty or aesthetic appreciation and inspiration for culture, art and design.
- “Spiritual or emblematic value”: Holy or spiritual places important to spiritual or ritual identity and sense of belonging; presence of emblematic plants and animals.
- “Scientific investigation and traditional knowledge”: Knowledge systems (traditional and formal) based on ecosystems; subject matter for scientific research.
- “Education”: formal and informal education based on ecosystems; capacity to increase understanding of local species and ecosystems through the direct observation and experience of nature.
- “Community benefits”: Social relations influenced by local ecosystems; sites for festivals or community meetings.

Overall, 16 out of 42 UGS were mentioned as providers of any kind of cultural ES. Two of them were conservation areas (C1, the peri-urban forest in Mya Sein Mountain; and C3, the preserved area in the south of the city), 6 “General green areas”, 7 religious areas and one sportive area (Taunggyi football stadium). C1 was by far the most often mentioned UGS in the city, with 17 respondents referring to it, while the other areas received between 4 and 1 citation each (see Annex A for cultural ES scores per UGS).

In general, most participants ranked the importance for their personal wellbeing (demand indicator) in Taunggyi as high, with a mean value of 3.4 for all ES in a range of 1 to 5. The highest value (3.69) was earned by “Education”, followed by “Recreation” (3.67) and “Spiritual or emblematic value” (3.51), while the lowest one was “Community benefits” with a mean score of 3.08 (Fig. 8a). Respondents’ satisfaction level with the actual ES supply (supply indicator) was more variable and in general received lower values, scoring 2.7 on average with “Education” being the lowest with a mean value of 1.8 and “Spiritual or emblematic value” the highest with 3.78 (Fig. 8b).

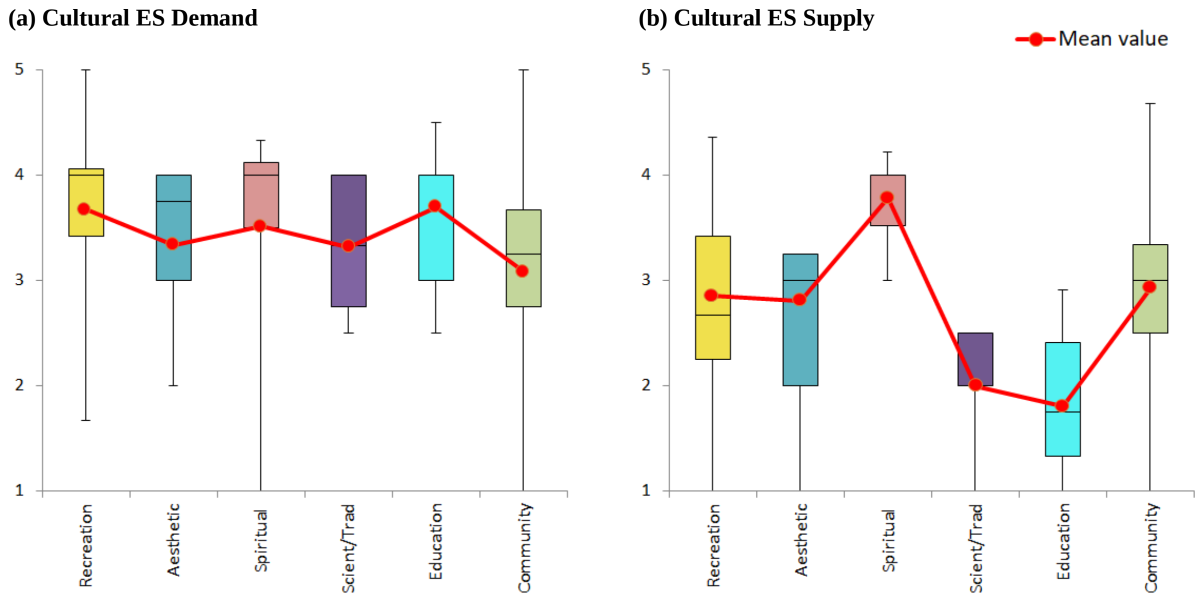

Figure 8: Boxplots and mean values of each cultural ES according to (a) the importance for respondents' wellbeing (Demand); and (b) satisfaction with current supply level (Supply).

Source: Author.

As previously mentioned, apart from the 1-5 scoring questionnaire respondents were asked to explain the reasons for the values they assigned to each of the UGS, with the aim of gaining understanding on the preferences and condition of cultural ES in Taunggyi. Even though C1 area, Mya Sein mountain, appeared as one of the most valued UGS in the city, most respondents pointed out certain aspects to improve their supply satisfaction scores. These were related to the lack of safety, damaged vegetation cover and loss of biodiversity (specially flowered species, whose aesthetic value is highly appreciated by citizens), lack of playgrounds and resting areas, and lack of street furniture (signals, benches, bins, etc.). The absence of adequate infrastructure was also mentioned in other important UGS in the core of the city, as Mya Kan Thar Park (G1), Bo Gyoke Aung San Park (G2), or the park around the Parliament (G3).

Lack of initiatives for developing educative, scientific or traditional knowledge activities was also mentioned for most UGS, however some respondents mentioned that NGOs and local communities had been recently working in Mya Sein Mountain and the park around the Parliament in activities such as tree planting, cleaning the area and even installing street furniture.

It can be noticed that "Spiritual or emblematic value" displayed the highest supply scores, due to the fact that green areas around pagodas are in general in good condition and serve properly their purpose, which is praying and hosting religious events 3-4 times a year (although some respondents also valued them for recreational uses as walking or meeting friends). Besides, apart from the religious UGS, conservation areas C1 and C3 also earned high scores for "Spiritual or emblematic value", because of the presence of Banyan trees which have great sacred and symbolic significance for the Buddhist and are supposed to be protected.

Therefore, the two cultural ES selected to develop a further analysis in this thesis were “Recreation” and “Education”, as they were considered of vital importance both by Ward representatives and expert consultation, and their supply scores in Taunggyi appeared to be far from meeting the actual demand.

4.3 ES Supply per UGS

The maps and descriptive statistics resulted from the input of ES scores to each UGS (Fig. 9, Table 7) show that every plot under study provides a relatively high amount of **Water provision** service, ranging from a minimum of 4524 m3 ha-1 year-1 (in the military area M01) to a maximum of 6510 m3 ha-1 year-1 (in UGS G11, one of the neighbourhood forest in the south of the city).

The values for **Urban temperature regulation** showed a slight variance among the different UGS in the city, with minimum scores of 1 ºC cooling capacity in the religious area R13 to a maximum value of 2.5 ºC assigned to four UGS (conservation areas C1 and C3, neighbourhood forest G16 and religious area R3). This is due to the fact that urban temperature regulation was calculated by a combined factor of the % of tree cover in each plot and the evaporation coefficient of its vegetation cover (which is higher for forests and lower for shrubs and paved areas). Hence, UGS which had 100% Forest cover earned the highest scores.

Regarding the indicator for **Global Climate regulation**, two UGS showed no contribution to carbon sequestration, as their vegetation cover is not formed by trees: the Football stadium (code S2) and the Fireballon launching site (G6). Conversely, the areas that make the greatest contribution for Global Climate regulation are again the most forested areas: two of the conservation areas (C1 and C3), the neighbourhood forest G16 and religious area R3, with a score of 15.8 t CO2 ha-1 year-1.

	Water provision (m3 ha-1 year-1)	Urban temperature regulation (ºC)	Global Climate regulation (t CO2 ha-1 year-1)	Recreation (1-5)	Education (1-5)
N Valid	43	43	43	15	13
N Missing	0	0	0	28	30
Mean	6102,4591	1,9170	8,5677	1,7227	1,2238
Std. Deviation	524,11610	,46542	5,26975	,70440	,36367
Minimum	4524,00	1,00	,00	1,00	1,00
Maximum	6509,84	2,50	15,77	3,59	2,41

Table 7: Descriptive statistics table of the five ES Supply indicators for the selected UGS in Taunggyi.

Source:Author.

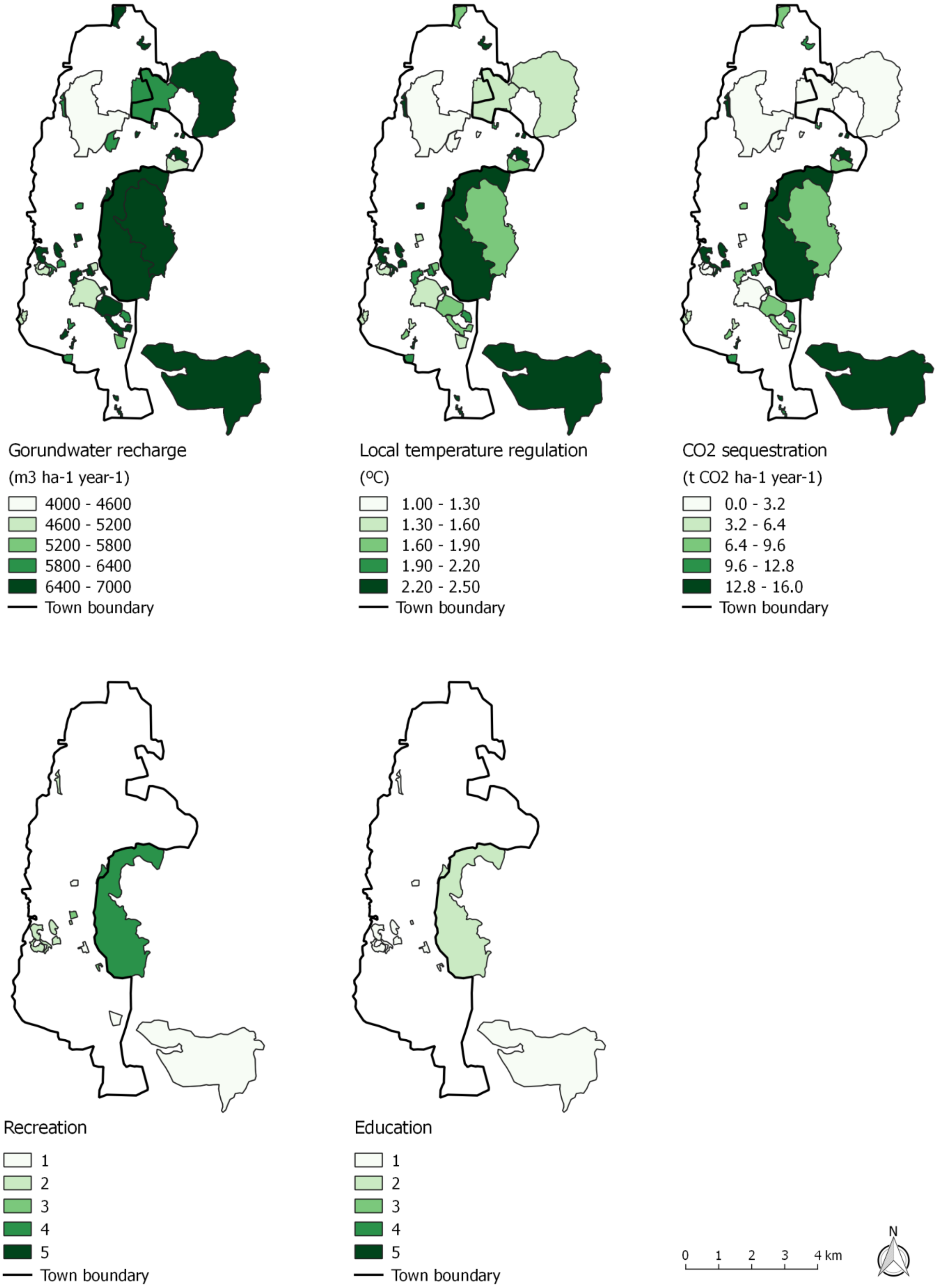

Figure 9: Maps of the five ES Supply indicators for the selected UGS in Taunggyi.

Source: Author.

With respect to the assessment of **cultural ES**, it was noted that according to the data collected from the questionnaires using ranges from 1 (Very low supply satisfaction) to 5 (Very high supply satisfaction), most UGS showed no supply for any of them, and the ones that were given some value scored rather low. In the case of the Recreation service, 15 UGS display certain amount of supply, ranging from score 1.00 in G19, one of the vacant lots, to 3.59 in C1, Mya Sein mountain forest. As for the Education ES, 13 plots provide some kind of this service, from a minimum of 1.00 in G19 and the conservation area C3; to a maximum of 2.41 again in the conservation area of Mya Sein mountain forest (C1).

The fact that the majority of the UGS presented to the respondents received no mention as providers of cultural services might respond to accessibility factors (in the case of military or sportive areas), to the lack of conditioning of most green vacant lots for cultural exploitation, or to the sampling used for the respondents, limited to ward representatives and possibly not completely reflecting the perceptions of the entire population. Indeed, conversations with younger local residents during the fieldwork revealed the importance for recreation purposes of certain UGS which were not mentioned by the questionnaire respondents, as the green areas around the University or other parks in the centre and south of the city.

4.4 ES Supply distribution

The second step in the analysis was to estimate the average supply scores for each ES in the different areas of Taunggyi. Fig. 10 and Table 8 reflect the results from the mapping and descriptive statistics for each of the 25 units of study in this research (22 city wards and the 3 main peri-urban green areas). As was expected, there is a relatively common pattern in all maps, with the peri-urban green areas scoring higher values than the wards in the urban core of Taunggyi.

It should be noted that, for the calculation of the ES supply indicators per ward, most values were taken just from UGS included within the boundaries of each ward or peri-urban area, except for Urban temperature regulation ES for which certain "cooling bands" on the surroundings of the UGS were also estimated depending on the size of each plot (see Annex B for additional calculation details).

Regarding the indicators for **Water provision** service, almost half the units under study (12) showed no contribution to this ES, as they have no UGS within their limits. On the opposite, the three natural areas in the urban fringe earned the highest scores, with a maximum of 6493 m3 ha-1 year-1 in the peri-urban green area 3 in the south of the city, which is entirely composed by a forested conservation area.

With reference to the assessment of **Urban temperature regulation** ES, in which the cooling effect of the green areas over their surroundings was taken into account, it was noted that only four city wards scored null supply values, while the rest of the areas earned positive values up to a maximum of 2.5 ºC in the peri-urban green area 3. Green areas in the urban fringe showed the highest scores, while most populated wards in the urban core displayed lower values.

As concerns **Global Climate regulation** by carbon sequestration, all the spatial units showed rather low supply scores, with 12 of them making no contribution at all (0 t CO_2 ha-1 year-1). The only exceptions were the green areas in the north and south limits of the city, with again the peri-urban green area 3 scoring a maximum of 15.77 t CO_2 ha-1 year-1. As climate regulation is not an ES that affects in a local scale, the total amount of sequestrated CO_2 was also estimated, around 20,590 t CO_2 per year.

ES Supply	Water provision (m3 ha-1 year-1)	Urban temperature regulation (ºC)	Global Climate regulation (t CO2 ha-1 year-1)	Recreation (1-5)	Education (1-5)
N Valid	25	25	25	25	25
N Missing	0	0	0	0	0
Mean	1140,6872	,8188	1,7136	1,2284	1,0768
Std. Deviation	1983,96334	,75233	3,87932	,56184	,28188
Minimum	,00	,00	,00	1,00	1,00
Maximum	6493,00	2,50	15,77	3,59	2,41

Table 8: Descriptive statistics table of the five ES Supply indicators in the different areas of Taunggyi.

Source:Author.

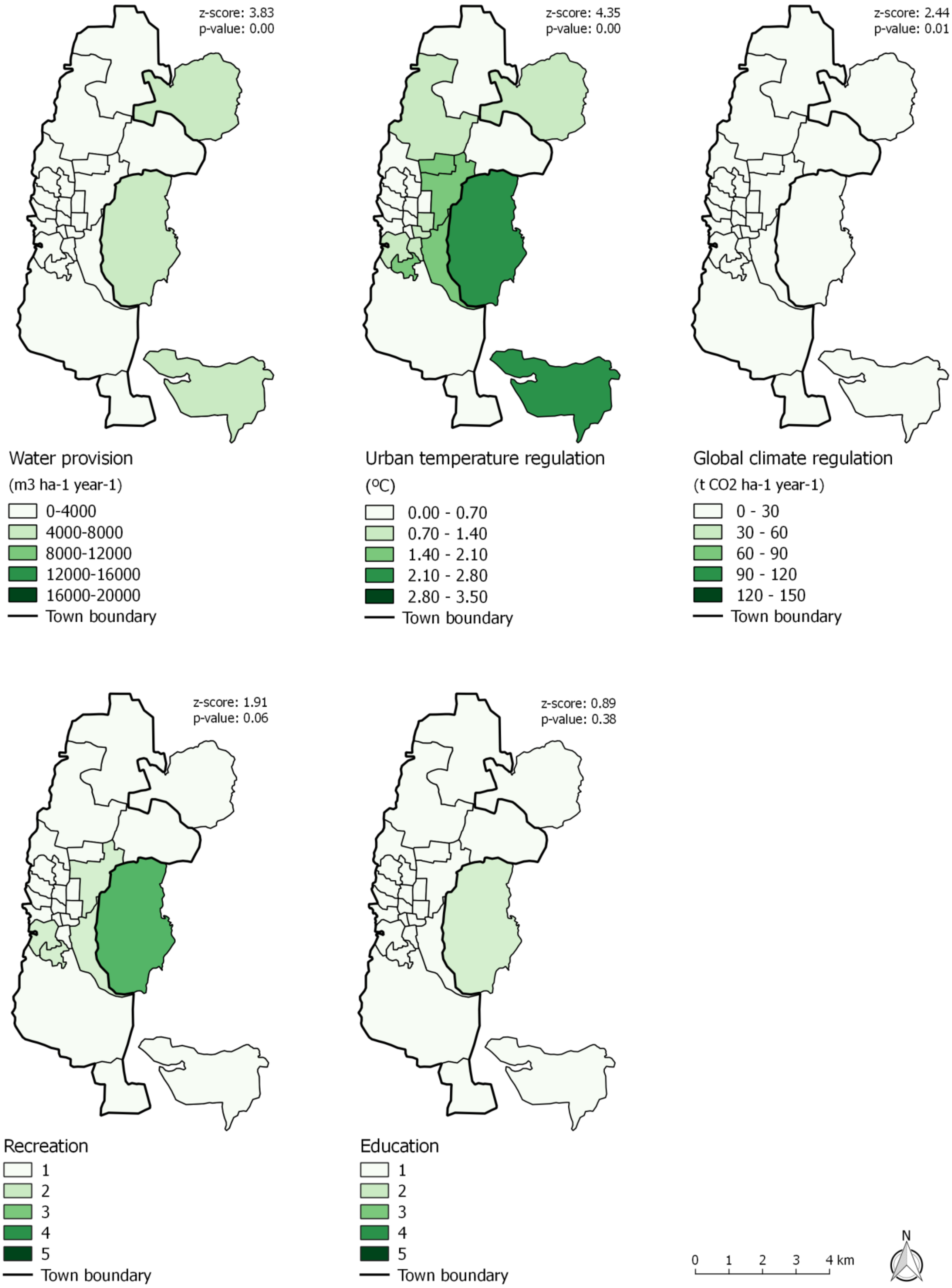

Figure 10: Spatial patterns and spatial clustering values (z-score) of the five ES Supply indicators in Taunggyi.

Source: Author.

With respect to the assessment of **cultural ES**, all areas scored rather low for both indicators. In the case of Recreation, 18 wards showed the minimum value (1 or "Very low supply satisfaction"), either because they had no UGS providing this service or because, even if they had it, the proportion of green area with respect to the total area of the ward was so small that the ES value was reduced to the minimum (see Table B8 in Annex B for calculation details). The maximum value, 3.59 in a range from 1 to 5, was earned by the peri-urban green area 1, because of the relatively high scores given by questionnaire respondents to Mya Sein mountain forest. As for Education ES, 20 areas displayed 1 ("Very low supply satisfaction"), and the maximum score by the peri-urban green area 1 was 2.41.

In terms of the spatial distribution of the different ES supply among the city, the results from the **spatial autocorrelation analysis** showed that the indicators for provisioning and regulating ES and are significantly clustered in the city (z-score > 1.96), as they showed p-values below 0.05 and z-scores indicate that there is less than 1% (Water provision and Urban temperature regulation) or 5% (Global Climate regulation) likelihood that their clustered spatial pattern is the result of random chance. On the contrary, Education ES showed a random distribution, with a p-value over 0.05 (p-value = 0.38) and a low z-score (0.89) indicating that the pattern does not appear to be significantly different than random. Recreation ES displayed a slightly clustered spatial arrangement; however its p-value is also over 0.05 (p-value = 0.06) and its z-score is under 1.96 (z-score = 1.91) hence the results in this case are not considered significant (Fig. 10).

Regarding the **correlation between pairs of ES** supply indicators developed to identify potential synergies or tradeoffs among them, results from the Pearson correlation analysis in SPSS showed that all ES supply indicators are significantly and positively correlated among them. Water provision and Recreation, as well as Urban temperature regulation and Education, are moderately positively correlated (Pearson coefficient > 0.3 and < 0.5); while all the rest of pairs of ES are highly positively correlated (Pearson coefficient > 0.5) (Table 9). Hence, it can be concluded that there are strong synergies among all the ES under study (they co-vary positively) and that none of them implies any relevant trade-off towards any other ES.

ES Supply	**Water provision**	**Urban temp. regulation**	**Global Climate regulation**	**Recreation**	**Education**
Water provision	1				
Urban temp. regulation	0.666**	1			
Global Climate regulation	0.868**	0.697**	1		
Recreation	0.499*	0.578**	0.552**	1	
Education	0.553**	0.438*	0.583**	0.918**	1

Table 9: Bivariate correlations (Pearson's R) between pairs of ES Supply indicators per ward (*P < 0.05, **P < 0.01).

Source:Author.

Finally, another method to identify ES associations was **"ES Supply richness"** analysis (Fig. 11), which represents the number of ES provided in each ward on a relevant amount (ES value equal or above the mean value). The analysis confirmed that the peri-urban green area 1, together with Chan Ther and Khan Ther wards, are the most multifunctional areas in Taunggyi in terms of ES Supply richness, providing a relevant amount of all five ES. Chan Ther and Khan Ther wards have a relatively high proportion id UGS area within their boundaries (19% and 24%, respectively), which might be related to these positive results. The other peri-urban green areas scored 3, while the less rich areas (score 0) were mostly located in the urban core of the city (although some wards in the urban fringe also scored low richness, as Phayar Pyu in the north and Kan Kyi in the south of Taunggyi city).

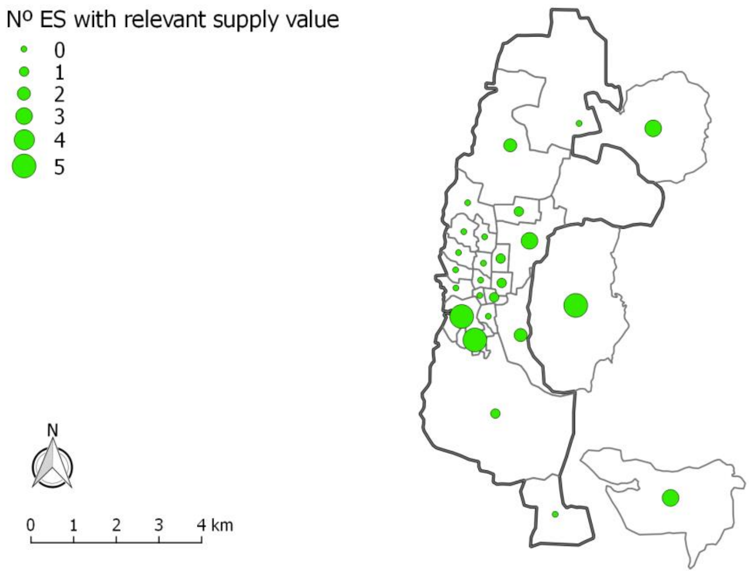

Figure 11: ES Supply richness map: number of ES with relevant supply per ward (value ≥ mean).

Source: Author.

4.5 ES Demand distribution

The same analysis was carried out but in this case to evaluate de ES Demand in Taunggyi in each of the 25 spatial units under study. As will be explained below, similar spatial patterns were found for the provisioning and regulating services, which show the highest demand in the urban core of the city; whereas cultural ES show a notably different pattern, more evenly distributed among the different areas of the city (Fig. 12).

With regard to the analysis of **Water provision** ES Demand in Taunggyi, all the wards showed a significant amount of water demand, while peri-urban green areas displayed no demand as no population was registered there. Among the urban wards, Shwe Taung, the most populated one (measured by population density) scored a maximum of 18696 m3 ha-1 year-1 water consumption, and Kan Kyi was the lowest with 843 m3 ha-1 year-1 (see Table 10 for a summary of the descriptive statistics of all ES).

In respect to **Urban temperature regulation**, values ranged from a minimum of 0ºC in nine wards, to a maximum of 3.23 ºC demand in Shwe Taung ward, which matches with the calculation method that estimates higher temperature increases in most densely populated urban areas.

Similarly, the assessment of **Global Climate regulation** ES showed the highest demand rates (or CO2 emissions) in the urban core, with a maximum of 142 t CO2 ha-1 year-1 again in Shwe Taung ward. Conversely, the three peri-urban green areas displayed no CO2 emissions (0 t CO2 ha-1 year-1). The total amount of CO2 emissions was also calculated in order to make a balance at the city scale, resulting in 64,388 t CO2 year-1.

ES Demand	Water provision (m3 ha-1 year-1)	Urban temperature regulation (ºC)	Global Climate regulation (t CO2 ha-1 year-1)	Recreation (1-5)	Education (1-5)
N Valid	25	25	25	25	25
N Missing	0	0	0	0	0
Mean	5899,6936	,5948	44,8348	3,5472	3,6084
Std. Deviation	4740,68896	,81894	36,02691	,88896	,84780
Minimum	,00	,00	,00	1,00	1,00
Maximum	18696,20	3,23	142,08	4,59	4,60

Table 10: Descriptive statistics table of the five ES Demand indicators in the different areas of Taunggyi.

Source:Author.

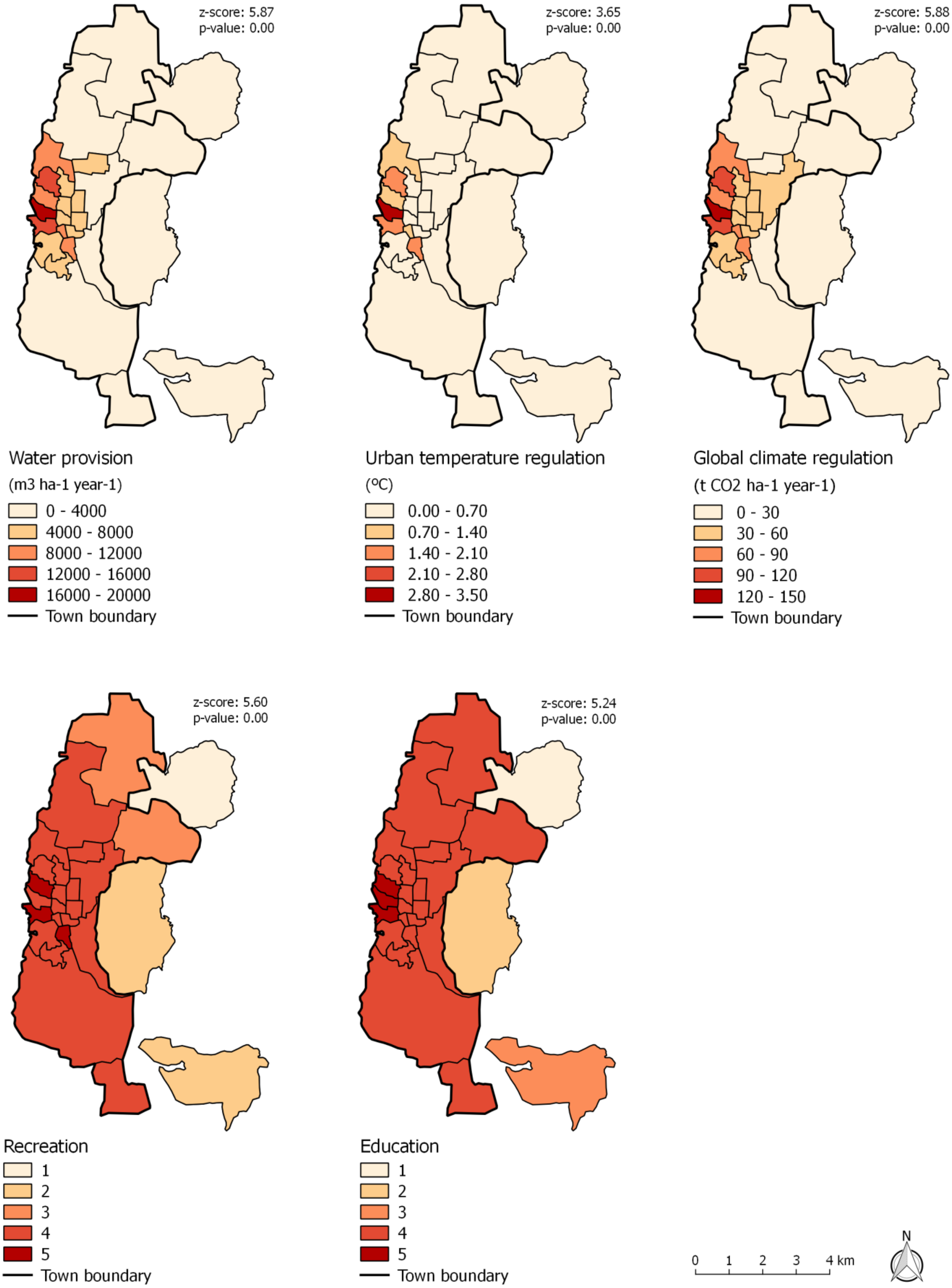

Figure 12: Spatial patterns and spatial clustering values (z-score) of the five ES Demand indicators in Taunggyi.

Source: Author.

As for the analysis of **cultural ES**, all the areas except for the peri-urban green areas showed a high demand level for both services. The highest score for Recreation was earned by Sein Pann ward, with 4.59 in a range from 1 (“Very low demand”) to 5 (“Very high demand”); and for Education the highest value was 4.60 in Shwe Taung ward. All the other urban wards scored above 3, and the minimum was for the peri-urban green area 2 with a value of 1 for both indicators.

Regarding the spatial pattern analysis of the ES Demand in Taunggyi, the **spatial autocorrelation analysis** indicated that the five ES indicators are significantly clustered in the city at the individual level (z-score > 1.96, Fig. 12). All of them showed p-values below 0.05 and their z-scores indicate that there is less than 1% probability that their clustered spatial pattern is the result of random chance.

In terms of the **correlation between pairs of ES** demand indicators, Pearson correlation analysis displayed that all the possible pairwise ES combinations are significantly and highly positively correlated, with Pearson coefficient > 0.5 and all p-values below 0.01 (Table 11). Water provision and Global climate regulation display a perfect positive linear relationship (Pearson coefficient = 1), which was expected as the indicators for both ES were based on per capita consumption levels (population per ward). Similarly to supply indicators, these results show that there are also significant synergies among all studied ES demand indicators.

ES Demand	Water provision	Urban temp. regulation	Global Climate regulation	Recreation	Education
Water provision	1				
Urban temp. regulation	0.948**	1			
Global Climate regulation	1**	0.948**	1		
Recreation	0.732**	0.552**	0.732**	1	
Education	0.724**	0.564**	0.724**	0.968**	1

Table 11: Bivariate correlations (Pearson’s R) between pairs of ES Supply indicators per ward (*P < 0.05, **P < 0.01).

Source:Author.

Lastly, **“ES Demand richness”** analysis confirmed that the urban core withstands the highest demand levels in most ES, with 5 wards showing a relevant demand (indicator value equal or above the mean value) for all five ES under study: Chan Myae Ther Si, Myo Ma, Nyaung Phyu, Sein Pann and Yandanar Thiri. Conversely, peri-urban areas as well as Hzay Paing and Nyaung Shwe Haw Kone wards, characterized by very low population densities, show no relevant demand in any of the five ES. (Fig. 13).

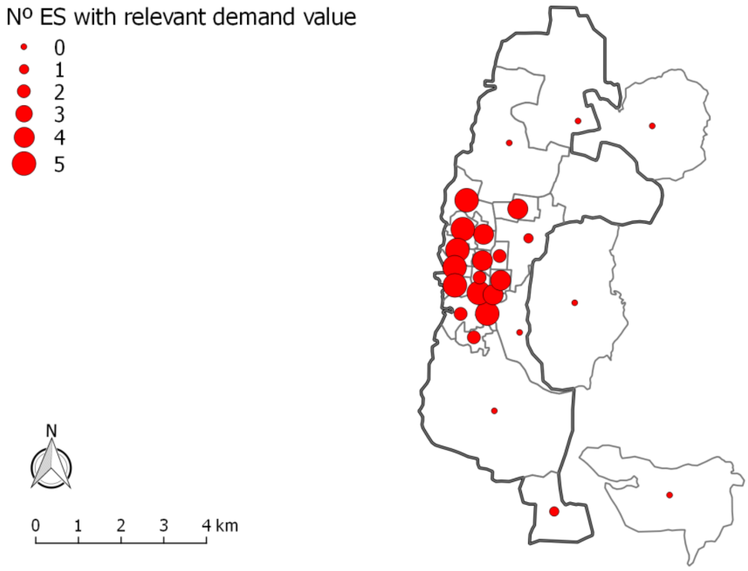

Figure 13: ES Demand richness map: number of ES with relevant demand per ward (value ≥ mean).

Source: Author.

4.6 ES Supply-Demand balance

The use of identical units of measurement for both supply and demand indicators for each ES enabled the comparison and quantification of the supply-demand balance in the area under study. Hence, the first step was to conduct an **overlap analysis** so that “greenspots” and “redspots” in the city could be easily identified in a map (Fig. 14).

As expected, wards in the urban core reflected a considerable mismatch as the demand was much higher than the supply for all ES, while only the peri-urban area 1, which includes the Mya Sein mountain forest, showed a higher supply than demand values for all of them.

The ward with the most negative balance was Shwe Taung, the most densely populated ward in the urban core, which depicted the lowest values for all ES (-18,696.2 m3 ha-1 year-1 for Water provision; -3.23 ºC for Urban temperature regulation; -142.1 t CO2 ha-1 year-1 for Global Climate regulation and -4 for Education) except for Recreation (score -3) (see tables in Annex B for calculation details and final scores per ward).

On the contrary, the three peri-urban green areas revealed the most positive balance values for all the studied ES except for Urban temperature regulation, in which some wards (Yay aye Kwin and Thit Taw) showed higher values than the peri-urban natural area 2 due to the influence of Mya Sein mountain forest on its surroundings.

Urban temperature regulation was the only ES demand that appears mostly covered by ES supply in the city (except for the wards in the urban core), while Recreation and Education ES present the highest mismatch or unbalance from the supply-demand perspective in Taunggyi city.

Overall figures for the ES supply/demand balance at the urban level, that is, of Taunggyi city as a single entity, were also estimated for the ES that could be mathematically aggregated, obtaining the following results:

- Water provision: + 5,384,762 m3 year-1. Even though most areas in the city appeared to have a greater water demand than supply value, the contribution from the three main peri-urban green areas generated an overall positive balance in the city.

- Global climate regulation: - 43,798 t CO2 year-1. According to the estimations in this research, the carbon sequestered by the urban and peri-urban green spaces in Taunggyi cannot compensate the current emission levels, showing an overall negative ES mismatch from the supply/demand perspective.

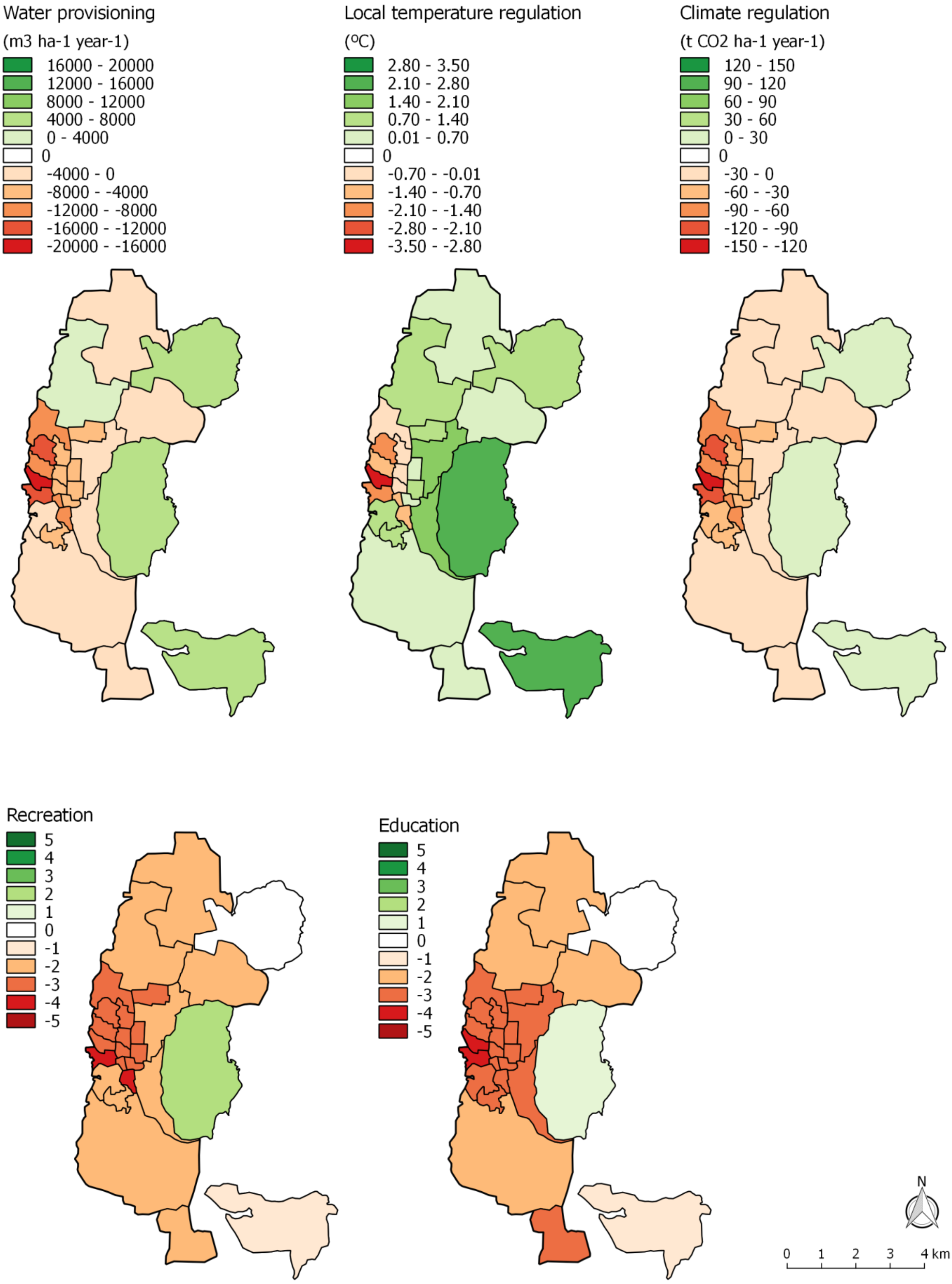

Figure 14: Spatial pattern of the Supply-Demand balance for the five ES indicators in Taunggyi.

Source: Author.

Finally, a **cluster analysis** was developed to classify wards with similar ES bundle types regarding both ES supply and demand scores. Wards were grouped into 5 different supply-demand bundle types using K-means clustering algorithm in SPSS (Fig. 15, Table 12). **Spatial autocorrelation analysis** showed that these clusters are also spatially grouped in the study area (z-score = 6.5 > 1.96, p-value = 0.00 < 0.05), which indicates that there is less than 1% likelihood that their clustered spatial pattern is the result of random chance.

- Cluster A: peri-urban green areas (3 areas).

This cluster corresponds to the three peri-urban green areas included in the research, which include the conservation areas and some military and agricultural areas adjacent to them. As expected, this cluster shows the highest supply scores for all five ES, and the lowest demand values (0 for the provisioning and regulating ES, and 1-or "very low"- for the cultural services).

- Cluster B: peripheral wards (6 wards).

The second bundle type includes urban areas in the north and south boundaries of the city, as well as the wards adjacent to Shwe Bone Pwint mountain. These wards are characterized by a relatively low population density and higher proportion of UGS, hence its scores display medium values in the ES supply and low demand for provisioning and regulating ES. Cultural ES are highly demanded in all clusters, as most respondents from the questionnaire stated that these services were very important for their wellbeing and that their actual satisfaction level was low.

- Cluster C: urban core (11 wards).

This cluster englobes the majority of the wards in the urban core of Taunggyi, which have a relevant amount of population and low proportion of UGS in most cases. It shows low ES supply scores for all services and moderate demand for them (except for cultural ES which are also high).

- Cluster D: densest wards in the urban core (4 wards).

The next bundle type corresponds to some of the densest wards in the city (between 185 and 229 pers/ha) with no relevant UGS within their boundaries. Consequently, it displays the lowest values for ES supply indicators (0 for provisioning and regulating ES, 1 or "very low" for cultural ES), and very high demand values for all ES. Hence, these areas present a clear mismatch from the supply-demand perspective.

- Cluster E: Shwe Taung (1 ward).

The last typology corresponds to a unique ward, Shwe Taung, which has similar characteristics to the previous cluster D, but it has an even higher population density (338 pers/ha), and also no UGS within its boundaries. ES supply-demand relationships are then highly unbalanced, with the lowest ES supply scores and maximum demand values for all ES.

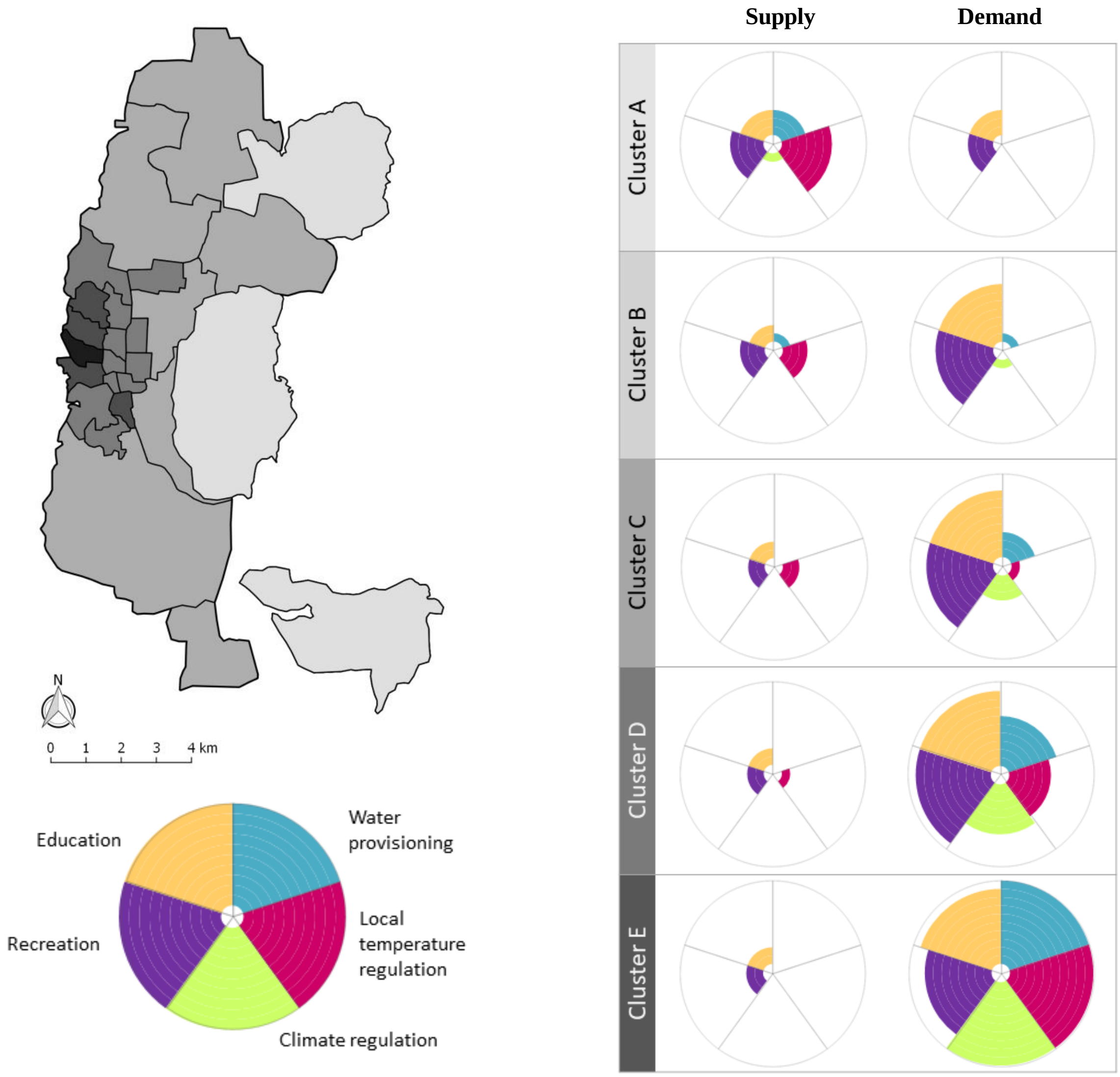

Figure 15: Spatial distribution of ES Supply-Demand bundle types and standardized mean scores for each cluster (represented in rosette diagrams).

Source: Author.

		Cluster				
		A (n=3)	**B (n=6)**	**C (n=11)**	**D (n=4)**	**E (n=1)**
Water provision	Supply	6079,10	962,63	409,47	0,00	0,00
	Demand	0,00	1819,66	6434,88	11773,62	18696,20
Urban temp. regulation	Supply	1,99	1,02	0,69	0,20	0,00
	Demand	0,00	0,00	0,45	1,66	3,23
Global Climate regulation	Supply	10,04	0,84	0,70	0,00	0,00
	Demand	0,00	13,83	48,90	89,48	142,08
Recreation	Supply	1,88	1,26	1,14	1,00	1,00
	Demand	1,42	3,40	3,83	4,44	4,20
Education	Supply	1,47	1,03	1,03	1,00	1,00
	Demand	1,57	3,53	3,85	4,34	4,60

Table 12: Mean values for each ES indicator within each of the clusters or supply-demand bundle types. N indicates the number of wards per cluster.

Source:Author.

4.7 Potential influential factor analysis

Finally, statistical analysis was carried out using SPSS software in order to identify potential **factors that might influence the ES supply by UGS**, using the information available for this study. The independent variables or factors were the UGS area, Land Use type, Land Cover type, and Accessibility (whether it is public and free, or not), while the dependent variables were the selected five ES supply indicators per UGS (Water provision, Temperature regulation, CO2 sequestration, Recreation and Education).

Linear regression analysis was used to study the effect of UGS **Area** on their capacity for ES supply. It was found that there is a non-significant relationship among these variables, as UGS area did not predict any of the five ES supply indicators ($p > .05$) (see Annex C for SPSS output tables).

In the case of **Accessibility**, a **T-test** was carried out in order to analyse its influence on ES provision level per UGS. In all cases except for Water provision indicator, Levene’s Test was non-significant ($p > .05$) hence equal variances could be assumed; however T-test results showed that there is no significant difference between accessible and non-accessible UGS in their ES provision scores ($p > .05$). Therefore, it can be assumed that Accessibility is also not an influential factor for ES Supply.

With regards to **Land Use** and **Land Cover** type, as they are nominal variables with more than 2 categories, ANOVA tests were developed for their analysis. First, a **Levene's test** was run and showed that only Global Climate regulation met the assumption of homogeneity of variance ($p > .05$), hence a **one-way ANOVA** was conducted and a significant result was found for Land Cover variable and Global Climate regulation (F = 64,869, p = 0.00), meaning that Land Cover typology significantly affects the supply level of Global Climate regulation by UGS (see Annex C for SPSS output tables). In the case of Land Use variable, the relation was found non-significant.

Afterwards, a **Tukey's B** Post Hoc test was carried to confirm where the differences occurred between the different Land Cover typologies for Global Climate regulation. The test showed that Grasslands are the lowest providers for CO2 sequestration (0.5 t CO2 ha-1 year-1) and Forests are the highest (13.4 t CO2 ha-1 year-1). Mosaics of Trees and grass and Trees and shrubs conform a middle range, with scores of 7.5 t CO2 ha-1 year-1 and 7.6 t CO2 ha-1 year-1 respectively, and other mixed vegetation covers earned lower scores (Table 13). This matches with the calculation methodology used, which measured sequestration capacity by the proportion of tree cover in each UGS.

LandCover_2 Land Cover	N	Subset for alpha = 0.05		
		1	2	3
6 Grassland	3	,5267		
4 Shrubland	3	1,5800		
5 Mosaic herbaceous	2	2,0150		
7 Paved-Mixed vegetation	5	2,8380		
3 Mosaic Tree-Grass	4		7,5300	
2 Mosaic Tree-Shrub	6		7,6183	
1 Forest	20			13,4020

Table 13: Tukey B test results for Land Cover typology and Global Climate regulation ES. Means for groups in homogeneous subsets are displayed.

Source:Author.

For the rest of variables, which violated the assumption of homogeneity of variance (p < .05 in Levene's test) and normal data distribution also could not be assumed; a non-parametric **Kruskal-Wallis test** was conducted for their analysis. Different **Land Use** typologies were found to be statistically significant for Water provision capacity ($\chi 2(2)$ = 14.382, *p* = 0.026) (see Annex C for SPSS output tables); with Neighbourhood forests showing the highest scores and City Parks the lowest ones (Table 14).

	Land Use	N	Mean Rank
Water provision	1 Conservation	3	34,33
	2 City Park	4	12,75
	3 Neighbourhood forest	3	40,17
	4 Institutional	9	16,89
	5 Religious	13	18,85
	6 Sportive	2	22,50
	7 Vacant	9	25,50
	Total	43	

Table 14: Mean rank for Water Provision values by different Land Use typologies according to Kruskal-Wallis test.

Source:Author.

As for **Land Cover** typologies, according to Kruskal-Wallis test they displayed statistically significant differences for both Water provision ($\chi 2(2)$ = 20.563, *p* = 0.002) and Urban temperature regulation ($\chi 2(2)$ = 36.591, *p* = 0.000) indicators. For both services, UGS within the "Forest" category earned the highest values, as can be observed in the ranks from Table 15:

	Land Cover	N	Mean Rank
Water provision	1 Forest	20	29,20
	2 Mosaic Tree-Shrub	6	23,00
	3 Mosaic Tree-Grass	4	22,25
	4 Shrubland	3	16,33
	5 Mosaic herbaceous	2	15,75
	6 Grassland	3	12,83
	7 Paved-Mixed vegetation	5	3,20
	Total	43	
Urban temperature regulation	1 Forest	20	33,50
	2 Mosaic Tree-Shrub	6	17,50
	3 Mosaic Tree-Grass	4	20,00
	4 Shrubland	3	3,50
	5 Mosaic herbaceous	2	7,00
	6 Grassland	3	7,83
	7 Paved-Mixed vegetation	5	8,60
	Total	43	

Table 15: Mean rank for Water Provision and Temperature regulation values by different Land Cover typologies according to Kruskal-Wallis test.

Source:Author.

Hence, according to the developed statistical analysis, it could be assumed that Land Cover is a relevant influential factor for the ES supply by UGS, but only for three of the services analysed in this thesis (Global Climate regulation, Water Provision and Temperature regulation). Land Use typology also showed a significant result for its influence on Water Provision service. On the contrary, UGS area and Accessibility appear not to be influential on the supply levels of any of the ES investigated.

4.8 Findings overview and analysis

Supply – Demand analysis

Results obtained from this research showed that the five ES analysed are highly associated, showing similar spatial distribution patterns and significant positive correlation values overall.

As expected, **highest demand** rates for almost all ES were found in **densely populated wards** in the urban core of Taunggyi city. Moreover, it is precisely in these dense wards, with more than half of them containing no UGS within their boundaries, where the **lack of green** contributes to a **high negative mismatch** from the ES Supply-Demand perspective.

Conversely, the main providers of ES are located in the peri-urban fringe of the city, where the urbanizing pressure is much lower and local authorities have already taken measures to protect certain natural areas. Additionally, smaller forested parks located in the urban core of the city also showed high values on a wide range of ES supply, agreeing with the existing body of literature about the **multiple and varied ES that UGS might provide** at urban environments when they are correctly managed (Gaston et al. 2013; Bolund and Hunhammar 1999; Gómez-Baggethun and Barton 2013; Haase et al. 2014; Akbari 2002).

Although a specific rural-urban gradient analysis per se was not developed in this thesis, ES clusters seem to reflect a pattern similar to previous studies on urban regions (Kroll et al. 2012; Larondelle and Haase 2013), sine for most ES indicators, the highest demand values were located at the urban core and showed a decreasing pattern as the distance from the centre increased. On the contrary, supply values achieved the highest scores in peri-urban areas, with much lower values in the urban core.

This trend of finding opposite results in the urban core and the periphery of the city was confirmed by the spatial autocorrelation analysis carried out for both supply and demand indicators, which showed that **most ES are significantly spatially clustered in the city** at the individual level (z-score > 1.96), as previous research also highlight (Bennett et al. 2009; Haase and Schwarz 2012; Raudsepp-Hearne et al. 2010; Baró et al. 2017; Kong et al. 2018). Particularly **provisioning and regulating services appear with very similar supply-demand patterns**, while cultural ES seem slightly different since their supply is lower than the other ES in the overall extension of the city and their demand appears to be higher, and more evenly distributed.

From the Supply perspective, these results can be interpreted by the fact that provisioning and regulating ES Supply indicators were calculated by biophysical characteristics (UGS size, Land Cover, climatic conditions, etc.), whereas cultural ES were measured through citizens' preference or "Supply satisfaction" assessment. Results displaying low values for cultural ES provision suggest that, even if some UGS might be located in strategic centric locations in the city, currently they are **not sufficiently conditioned or accessible enough** for residents to use them for recreational, educational or other **cultural purposes**.

Indeed, this was confirmed by the qualitative descriptions given by Ward representatives, which explained that they were giving low scores to some UGS due to diverse factors as lack of safety and accessibility; absence of adequate infrastructure, playgrounds and resting areas; damaged vegetation; or lack of initiatives for developing educative or scientific activities within the UGS. These facts highlight the **importance of a correct management of UGS** in order to recover and enhance their potential benefits (Livesley et al. 2016)**.**

These low supply scores for cultural ES are combined by a high demand for them indicated by most Ward representatives, which stated that this kind of benefits provided by UGS are “Important” (score 4) or “Very important” (score 5) for their wellbeing, leading to a significant supply-demand mismatch in most areas of the city.

Results for **cultural ES demand in Taunggyi calls into question the pattern** observed by previous researches, in which **developing countries tend to prioritize provisioning services** over regulating and cultural services (Kendal, Martinez-Harms and Dobbs in Ferrini et al. 2017). In this case, considering the results obtained from questionnaires to Ward representatives, provisioning ES (score 4.9) did receive a higher score than the other two (regulating 4.8; cultural 4.6), however the difference is almost insignificant, just a few tenths in a score on a range from 1 to 5. This might be due to the quality of life in Taunggyi city, a state capital with a positive economic development, which is higher than the average expected for a developing country, together with the fact that all respondents were Ward representatives, which generally hold higher education levels and thus tend to show also higher environmental awareness and recognise a wider range of ES (Arcury 1990; Abdul-Wahab and Abdo 2010): since services vital for their survival are mostly covered, it could be expected that they would give greater importance to other benefits as regulating and cultural ES.

As mentioned, according to the Supply-Demand overlap analysis both Water provision and Global climate regulation ES appear to suffer from a general negative mismatch, since most areas in Taunggyi show higher demand than supply. However, considering the aggregated figures for both indicators at the city level, it was found that in the case of **Water provision ES, there is a surplus of 5,384,762 m3 year-1**, thanks to the essential contribution of peri-urban green spaces included in the study. This result highlights the essential contribution of peri-urban forests for climate resilience already pointed out by several studies (Xue et al. 2015; Voskamp and Van de Ven 2015; Chen 2008). Nevertheless, it seems to contradict the actual water deficit stated by Taunggyi officers and citizens, so it must be interpreted with caution. First of all, calculations were made using the total annual precipitation level (1747 mm), although there are vast differences between the rainy and dry seasons (from 304mm rainfall in August to 2mm in January, according to local climatic data (FAO 2018a)). Besides, key influencing factors as runoff coefficient or subsurface geology were not known for the development of this study, hence it could be inferred that there is an important water surplus concentrated in the rainy season (June - October), while the **dry season** (November - May) is **characterized by water shortage** due to a substantial decrease in precipitations and hence in aquifer storage level. As stated by residents and local authorities, population growth for the last decades in the city provoked an increasing pressure on groundwater extraction through over-pumping, which might led to undesirable effects specially in the dry season, such as water level declines (which brings increased pumping costs or dried up wells), reduced streamflow and degradation of water quality (Glasser et al. 2007).

On the contrary, **Global climate regulation ES showed a deficit of -43,798 t CO2 year-1**, which means that the carbon sequestered by the urban and peri-urban green spaces in Taunggyi cannot compensate the current emission levels. This result is consistent with previous results in most urban areas, which generally do not achieve a net zero carbon footprint (Escobedo et al. 2011; Liu and Li 2012; Nowak et al. 2013). Moreover, it must be noted that the CO2 emission rate in Myanmar, which is **0.417 metric tons per capita** according to World Bank database (https://data.worldbank.org/country/myanmar), is among the **lowest carbon emitting countries in the world**, and is around ten times inferior than the global average, 4.97 metric tons per capita (http://www.globalcarbonatlas.org/en/CO2-emissions).

Regarding **Urban temperature regulation**, the Supply-Demand overlap analysis depicted a **positive balance in most wards** of the city (except for the most populated ones in the urban core), which might be related to the fact that not only UGS but also their cooling effect over their surroundings was taken into account, hence higher values were achieved in most wards. Even though Taunggyi is not currently suffering from extreme weather conditions (minimum and maximum temperatures throughout the year are around 8.2ºC and 29.9ºC respectively), studies show an increasing trend on both maximum and minimum temperatures over the last 35 years (Zin et al. 2017), and according to predictions from Myanmar's National Adaptation Programme of Action to Climate Change (NECC and MECF 2012), annual mean temperature in the area is expected to rise up to 3.1ºC from baseline level (1971-2000) to the 2051-2099 period. Thus, although currently it appears not to imply a serious hazard, Urban temperature regulation by UGS is also a vital ES to maintain the current favourable local climate conditions in Taunggyi.

As concerns the examination of associations among ES, apart from spatial autocorrelation analysis **correlation between pairs of indicators** were also analysed, and all possible pairwise comparisons were found to be significant and positive, this is, there are **synergies among all ES indicators.** Previous research show that, most often, provisioning regulating and cultural ES are positively correlated, while trade-offs appear mostly towards provisioning services (Raudsepp-Hearne et al. 2010; Turner et al. 2014; Kong et al. 2018). This is mostly related to agricultural landscapes, which are commonly characterized by a low biodiversity and offer few options for cultural utilization, comparing to natural landscapes. As agricultural areas are out of the scope of this study and Water provision ES is provided by any UGS, in this case it is not surprising to find it positively correlated to other regulating and cultural ES.

Finally, K-means **Cluster analysis** helped identifying groups with similar ES bundle types regarding both ES supply and demand scores, from one end corresponding to the areas with the greatest supply and lowest demand (Cluster A), to the opposite one that suffers the most negative balance, with high demand and minimum (or null) ES supply (Cluster E). Not surprisingly, the three peri-urban green areas analysed in this study fell under Cluster A, whereas Cluster E was only composed by a single ward, Shwe Taung, which has the highest population density in Taunggyi and no UGS within its boundaries. It was found that Cluster typologies were also spatially grouped in the city ($z\text{-score} = 6.5 > 1.96$, $p\text{-value} = 0.00 < 0.05$), with typologies A and B located in the periphery, followed by cluster C in an intermediate zone, and finally D and E in the urban core of Taunggyi. Spatial autocorrelation was partially expected, as similar studies showed substantial spatial clustering among ES supply and/or demand indicators (Baró et al. 2017; Roces-Díaz et al. 2018; Zhang et al. 2018; Turner et al. 2014).

Potential influential factor analysis

Finally, about the statistical analysis to identify potential **factors that might influence the ES supply by UGS**, it was found through a one-way ANOVA test that **Land Cover** typology significantly predicts the supply level of **Global Climate regulation** by UGS (F = 64,869, p

= 0.00). In this regard, forests appeared as the main providers of this ES (mean value 13.4 t CO2 ha-1 year-1), followed by Mosaics of Trees and grass and Trees and shrubs. For the rest of variables which violated the assumption of homogeneity of variance, a Kruskal-Wallis test was conducted and Land Cover appeared to be statistically significant for both **Water provision** ($\chi2(2)$ = 20.563, p = 0.002) and **Urban temperature regulation** ($\chi2(2)$ = 36.591, p = 0.000) indicators, again with UGS within the "Forest" category earning the highest supply values. These results might be related to the calculation methods employed in this thesis for ES supply indicators, mostly based on the ecologic processes characteristic of each Land Cover type (rain water interception value, vegetation evapotranspiration coefficient, tree cover shading or carbon sequester by trees).

As for **Land Use** typologies, they were found to be statistically significant for **Water provision** capacity ($\chi2(2)$ = 14.382, p = 0.026) with Neighbourhood forests and Conservation areas showing the highest scores. However, these results might be more related to the forested vegetation cover rather than the Land Use itself.

On the other hand, the two other factors included in the study showed non-significant results ($p > .05$), hence it was concluded that not "UGS area" or "Accessibility" (whether the UGS access is public and free or not) predict any of the five ES supply indicators.

Chapter 5: Conclusions and recommendations

5.1 Introduction

The main objective of this thesis was to assess the ES supply-demand balance in Taunggyi by the identification, mapping and evaluation of a representative set of relevant ES for this context. ES assessments have proved to be a key tool to evaluate and measure the capacity of UGS to enhance environmental quality, climate resilience and human well-being in cities (Haase et al. 2014; Wolff et al. 2015; Maes et al. 2016), and the spatial visualization of the Supply-Demand balance throughout the different areas in the city enable a clear identification of the most needed areas and services, as well as the spots of greatest value in order to inform future decision-making about the urban development of the city and region.

Moreover, potential factors that might interfere in the ES supply were identified and analysed in order to deepen the understanding of the associations between biophysical facts or dynamics and the capacity of UGS to provide certain ES.

Among the multiple potential ES that could be examined in order to carry out this research, five were selected to perform the final supply-demand analysis, according to their relevance to the context of Taunggyi, data availability, and the aim of including at least one service from each of the three ES categories proposed by CICES classification (provisioning, regulating and cultural services). Therefore, the selected ES were (1) Water provision; (2) Urban temperature regulation; (3) Global Climate regulation; (4) Recreation; and (5) Education.

Regarding the strategy employed for identifying and quantifying associations between ES, the approach in this thesis was based on previous methodological frameworks (Mouchet et al. 2014), and included the following analyses: Spatial autocorrelation, Pairwise correlation, ES "Richness" calculation and Overlap analysis (this for supply-demand balance estimation).

As previously stated, lack of time and local statistical data were major challenges to accurately quantify ES supply and demand indicators in the study area. However, even with that constraint, this analysis helps to broadly identify several patterns related to the ES supply-demand balance distribution in Taunggyi, together with identifying the main gaps for future research and policy development in order to make the city more liveable and resilient for future challenges.

5.2 Conclusions and discussion

The results obtained from this research will be discussed as answers for the research question and sub-questions, including a discussion on their suitability and linking back to the literature references mentioned in previous chapters.

- **Research question 1: Which are the main green spaces in Taunggyi and how is the ES Supply distributed in the city?**

Taunggyi city is characterized by a very dense urban pattern with scarce green areas, particularly in the urban core. The number and size of UGS increment towards the outskirts of the city, with three important peri-urban forests and conservation areas in the East border of the town boundary. Most of the 43 analysed plots had a forested Land Cover (47%), and the most common Land Use was "Religious" (30% of the total).

The **ES Supply analysis per UGS** remarked that **peri-urban UGS**, in particular forested conservation areas C1 (Mya Sein mountain forest) and C3 (south east of the city), are the **main providers of provisioning and regulating ES**: Water provision (6493 m3 ha-1 year-1), Urban temperature regulation (2.5 ºC) and Global Climate regulation (15.8 t CO2 ha-1 year-1). Smaller forested areas in the urban core also received high scores for these ES, although their overall importance is not so significant due to their relative small area.

According to the results from the questionnaires to Ward representatives about their "Supply satisfaction level" for **Cultural ES**, **most UGS showed no supply at all**, and even the maximum values, earned by Mya Sein mountain forest (C1), were not so significant: 3.59 for Recreation and 2.41 for Education, in a range from 1 (Very low) to 5 (Very high). Nevertheless, it must be noted that the sample size (one representative from each Ward) might have led to low representative results, and indeed conversations with young local residents during the fieldwork revealed the importance of certain UGS which were not mentioned by questionnaire respondents, as the green areas around the University.

In respect to the spatial **distribution of ES Supply** along the different wards of the city, it appeared to be inversely related to the urbanization level in the city: **centric urban areas s**howed null or **very low scores**, especially for Water provision and Global Climate regulation indicators, while **peri-urban areas earned the highest supply scores**. The provision of Urban temperature regulation showed overall higher scores, as not only UGS area but also their surrounding cooling effect was taken into account; whereas cultural ES, displayed low scores for all wards, and regular values in the peri-urban green area 1 (which includes Mya Sein mountain forest and a forested military area). Consequently**, peri-urban areas** in Taunggyi (particularly peri-urban green area 1) were also **the most multifunctional** or "rich" areas in the city, providing a relevant amount of all five ES.

As expected, spatial autocorrelation analysis showed that **supply indicators for provisioning and regulating ES are significantly clustered in the city** (z-score > 1.96), reflecting their relation to UGS biophysical features which largely depend on whether the ward is located in the urban core (fewer UGS, lower Supply score) or on the periphery of the city (more UGS, higher Supply). On the contrary, **cultural ES supply indicators** do not only depend on the existence of UGS in each ward but in the satisfaction stated by respondents, hence their distribution **did not show a spatially clustered pattern** (z-score < 1.96).

About the relation among pairs of ES supply indicators, it was concluded that **there are synergies among all the ES supply indicators** selected for this thesis (Pearson coefficient > 0.3). These results suggest that all analysed ES depend on the same ecosystem processes or might be affected by common external factors (Bennett et al. 2009), which is what was intended to find through the "potential influential factor analysis" at the end of the study.

- **Research question 2: Which are the main Ecosystem Services demanded in Taunggyi and how is the ES Demand distributed in the city?**

All the five ES analysed in this research (Water provision; Urban temperature regulation; Global climate regulation; Recreation and Education) showed high demand values in the context of Taunggyi. During the preliminary expert consultation for ES prioritization, it was found that Water flow regulation, this is, flood risk mitigation, was also one of the most demanded ES (score 4.3 in a scale from 1 to 5), however it could not be included in this analysis due to important data limitations for the quantification methods.

Analysis of the ES Demand distribution in Taunggyi revealed greater variation in the scores of all indicators (wider range of values) comparing to ES Supply indicators. Overall, **similar spatial patterns were found for provisioning and regulating services**, with the **highest demand in the urban core** of the city and lowest in the outskirts; whereas Cultural ES showed higher scores and slightly more evenly distributed among the different areas of the city.

Wards in the urban centre displayed the highest demand for provisioning and regulating services, particularly Shwe Taung, the most densely populated ward (338.3 person/ha), which scored 18,696 m3 ha-1 year-1 for Water provision, 3.23 ºC for Urban temperature regulation, and 142 t CO2 ha-1 year-1 for Global Climate regulation. At the other end of the spectrum were peri-urban green areas, which showed no demand as no population was registered there.

Regarding **Cultural ES, all urban wards depicted high demand rates** (above 3 in a range from 1 to 5), with the highest score for Recreation in Sein Pann ward (score 4.59) and for Education in Shwe Taung ward (score 4.60), and the lowest demand scores earned by peri-urban green areas. The fact that Cultural ES Demand scores derived from a combination of population density and questionnaires' preference assessment (in which all respondents assigned scores of 4 or 5 to the "ES importance for their wellbeing"), resulted in values being more homogeneously distributed throughout the Wards of the city.

Pearson correlation analysis exposed that **all the possible pairwise ES combinations are significantly and highly positively correlated**, with Pearson coefficient > 0.5 and all p-values below 0.01, probably related to this research's calculation method, in which all ES demand indicators depend, to a greater or lesser extent, on population density values per ward.

Accordingly, all five ES **Demand indicators appeared to be significantly spatially clustered in the city**, showing p-values below 0.05 and z-scores over 1.96 indicating that there is less than 1% probability that their clustered spatial pattern is the result of random chance. Again, as population density increases with the proximity to the urban centre of Taunggyi, it was expected to find this kind of spatial clustering for most ES demand indicators.

- **Research question 3: How is the Ecosystem Services supply-demand balance distributed in Taunggyi and which factors might influence it?**

As expected, **densely populated wards in the urban core showed the highest negative mismatch for all ES**, while **peri-urban areas showed the highest positive ones**. However, only the peri-urban area 1, which includes the Mya Sein mountain forest, showed a higher supply than demand for five ES under study.

Shwe Taung, the most densely populated ward in the urban core, displayed the lowest values for all ES balance (-18,696.2 m3 ha-1 year-1 for Water provision; -3.23 ºC for Urban temperature regulation; -142.1 t CO2 ha-1 year-1 for Global Climate regulation and -4 for Education) except for Recreation (score -3). On the opposite end, the three peri-urban green areas revealed the most positive balance values for all the studied ES.

In the case of **Water provision**, although Supply-Demand balance map portrays a mostly negative mismatch in the context of Taunggyi, overall figures for the city show that there is a **surplus of 5,384,762 m3 year-1** of groundwater recharge. Nevertheless, as explained in the previous chapter, this does not reflect the variable precipitation pattern from the rainy to the dry season: while there might be a surplus for some months, the dry season is characterized by very scarce rains which lead to water provision shortage, which is worsened by urban densification trends. Therefore, control and management strategies for surface water and groundwater adapted to current and future demographic and economic development in Taunggyi are vital in order to ensure water security and sustainable development.

With regard to **Global climate regulation ES,** which showed a **deficit of -43,798 t CO2 year-1**, it is expected for an urban area not to compensate citizens' emission levels with the carbon sequestered by UGS (Escobedo et al. 2011; Liu and Li 2012; Nowak et al. 2013). Indeed, per capita carbon emissions in Myanmar are far below the world average, so the negative results obtained in this study should not lead to the assumption that Global climate regulation should be the main priority for Taunggyi. Nevertheless, economic growth, industrialization and urban development expected for the next decades in the country will probably entail an increment in CO2 emissions, hence appropriate financial flows, technology and capacity building should be delivered by developed countries in order to facilitate that countries like Myanmar can prosper in a sustainable way and increase their quality of life without severely harming global targets for climate change mitigation, as recommended by UNFCCC Paris Agreement (United Nations 2015).

Regarding **Urban temperature regulation**, the Supply-Demand overlap map reflected a **positive balance in most areas** of the city, which suggests that, for the moment, local climate regulation demand is mostly covered by the effect from UGS. However, the importance of maintaining these favourable conditions should not be underestimated given the predictions which foresee an increase up to 3.1ºC of the annual mean temperature from baseline level to the 2051-2099 period in Myanmar (NECC and MECF 2012). UGS are needed in the urban core to achieve a positive supply-demand balance, and the value of urban and peri-urban forests, irrespective of their scale, should be recognized and preserved in order to prevent future health damage derived from the Urban Heat Island effect.

Cultural ES showed the most negative mismatch or balance from the supply-demand perspective in Taunggyi city, as almost all areas, even in the peri-urban fringe, depict a higher demand than supply for both Recreation and Education ES indicators. Although this might seem surprising for a study on a developing country, in which provisioning ES tend to be prioritized over other services (Kendal, Martinez-Harms and Dobbs in Ferrini et al. 2017), results might be related to the profile of questionnaire respondents, which were Ward representatives with a higher education level and quality of life than the average in a developing country, hence more prone to give higher importance to cultural ES. Moreover, environmental awareness campaigns conducted by NGOs and educational institutions in the last years might have ignited a change of mentality among residents, and today more citizens are aware of the value of ecosystems both for their well-being and for climate resilience.

According to this study, Mya Sein mountain forest is the main provider both of Recreation and Education services, however citizens have to walk long distances in order to reach this peri-urban UGS, and **most respondents mentioned a number of aspects** that should be improved **for an enhanced cultural use** of this and other secondary green areas: lack of safety and accessibility; insufficient infrastructure, playgrounds and resting areas; damaged vegetation; or absence of initiatives for developing educative or scientific activities within the UGS. Hence, apart from increasing the number and spatial distribution of UGS conditioned for public use, the ones that are currently operational should be evaluated and managed regarding the needs and proposals stated by citizens.

Finally, **Cluster analysis** helped classifying urban wards according to their ES Supply-Demand balance, and confirmed the assumption that ES supply and demand indicators are closely associated to the land cover / land use and consequent socio-ecological characteristics of the urban fabric: as density increases and UGS percentage decreases, ES supply indicators decrease and demand grows.

Regarding the analysis of potential factors that might interfere in the ES supply by UGS, **Land Cover was found to be the most influential** one, mainly over Global Climate regulation but also over Water provision and Urban temperature regulation; and "Forest" typology was the one which earned the highest values for all three regulating and provisioning ES. **Land Use also significantly predicted** Water provision supply per UGS, with Neighbourhood forests and Conservation areas showing the highest scores. Conversely, "**UGS area" and "Accessibility"** appeared **not to have a significant relation** with any of the five ES supply indicators.

Surprisingly, none of the analysed factors appeared to significantly predict cultural ES supply, neither Recreation nor Education, although they revealed positively correlated to all other ES. According to literature, synergies among ES indicators are due to their dependence on the same ecosystem processes (UGS features), or because they might be affected by a common external factor (Bennett et al. 2009), hence further research should be carried out in order to detect the possible origin of these synergies.

Results from the "potential influential factor analysis" reflect the importance of urban forests for urban resilience and quality of life, in particular for benefits related to provisioning and regulating ES (in this case, Global Climate regulation, Water Provision and Temperature regulation), as has been defended by numerous academics and institutions (Nowak et al. 2013; Escobedo et al. 2011; Sanesi et al. 2017; Livesley et al. 2016). Since size appears not to be a significant influential factor, UGS management strategies should consider that forested areas, irrespective of their scale, in the urban and peri-urban areas, are essential features for climate resilience and water security of the city. However, further research on a wider range of ES would be necessary to confirm the validity of these outcomes, as other kind of vegetation cover might be more convenient for the delivery of different ES as food provision, pollination or flood control. ES Priorities set by local population and institutions should point out the services to analyse and guide the strategy for GI and urban development to be followed in the future.

As a conclusion, it can be stated that according to the ES Supply-Demand balance analysis performed in this study, there is a clear mismatch in the ES distribution throughout the city, since the most populated (hence most demanding) areas in the centre lack any relevant ES supply while the forested areas in the peri-urban fringe provide several ES although the demand there is much lower. In the case of provisioning and regulating ES this seems to be primarily related to the lack of UGS areas in the most centric wards, and in the case of cultural ES it appears to be also related to inadequate infrastructure and management in existing UGS, as wards with a considerable proportion of UGS also showed low cultural ES supply scores.

This kind of holistic and context-specific ES assessment might help building knowledge on the processes and synergies between ecosystems and socioeconomic systems, setting priorities and designing strategies to manage the nexus between UGS, water infrastructure and town planning, as a way to develop a resilient future enhancing environmental quality and human well-being in Taunggyi.

5.3Recommendations

From the analysis of the findings obtained in this thesis and in order to provide more robust knowledge and broader discussion on the conditions of ES supply-demand balance in Taunggyi, a series of recommendations for further research and policy development will be presented:

For future research:

- Perform similar studies and cross-city comparative research with other middle-sized cities in Myanmar, so as to get more generalizable results that could be useful for UGS management and urban planning in similar urban areas in the country.
- Carry out a more accurate study on the hydrological cycle and water provision in the context of Taunggyi and its region, including determining factors as slope, subsurface geology or depth of the water table, so as to evaluate its capacity and find the most suitable method to ensure water provision for current and future demand.
- Deepen the analysis of cultural ES supply-demand balance in Taunggyi expanding the sample size and selection by including different groups' interests, powers, relation and knowledge about the ecosystems, so that the results are more representative of the population as a whole. This could be delivered by a wider local residents' survey.
- Expand the study of ES with a more holistic approach including a broader range of services relevant for the specific context of Taunggyi, as flood protection, food provision or landslide prevention.

- Investigate on other potential factors that might cause the synergies among ES reflected in this ES, so as to enhance them and minimize potential trade-offs.
- Incorporate future simulations or scenario building depending on different development previsions in order to inform decision makers about the most convenient strategy for the context of Taunggyi.

For policy development:

- Protect the UGS that provide the greatest amount of ES, and carry out an adaptation and management plan for the ones with low supply scores
- Provide UGS with the required services and equipment regarding the needs and proposals already stated by local residents, so as to increase the supply of the most valued cultural services.
- Monitor and gather local data on indicators important for the ES assessment in Taunggyi and build empirically based evidence on urban ES.
- Plan a local or regional strategy for the measurement, control and management of water resources (both in the surface and underground), having into account future scenarios for demographic and economic development in Taunggyi. This should be accompanied by solutions for wastewater treatment and reuse, as well as water safety awareness programs.
- Extend town planning scope beyond municipal boundaries in order to better manage and control land use in peri-urban areas, which have proven to have an essential role for the equilibrium of urban areas), and link it to regional planning through multi-scale governance mechanisms.

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Annex A: ES prioritisation

Results from questionnaires to experts and Ward representatives, asked to assign the importance of each ES category from 1 (Very low) to 5 (Very high) in the context of Taunggyi:

	PROVISIONING	REGULATING	CULTURAL
Expert consultation			
City Development Committee (CDC)	4.00	3.16	3.13
Forestry Department	5.00	3.83	3.50
Department of Urban and Housing Development (DUHD)	5.00	3.16	3.75
Environmental Conservation Department (ECD)	5.00	3.67	4.38
Taunggyi Technological University environmental volunteering group	5.00	4.00	4.00
Average Expert consultation	**4.80**	**3.50**	**3.73**
Questionnaire to Ward representatives			
Chan Myae Ther Si	5,00	5,00	5,00
Chan Ther	5,00	5,00	5,00
Haw Kone	5,00	5,00	5,00
Hzay Paing	4,00	4,00	4,00
Kan Kyi	5,00	5,00	5,00
Kan Out	5,00	5,00	5,00
Kan Shae	5,00	5,00	5,00
Kan Ther	5,00	5,00	5,00
Kyaung Gyi Su	5,00	5,00	5,00
Lan Ma Taw	5,00	5,00	4,00
Mingalar Oo	5,00	5,00	4,00
Myo Ma	5,00	5,00	4,00
Nyaung Phyu	5,00	4,00	4,00
Nyaung Shwe Haw Kone	5,00	5,00	4,00
Phayar Phyu	4,00	4,00	4,00
Pyi Taw Ther	5,00	5,00	5,00
Sat Sen Htun	5,00	5,00	4,00
Sein Pann	5,00	5,00	5,00
Shwe Taung	5,00	5,00	5,00
Thit Taw	5,00	5,00	5,00
Yandanar Thiri	5,00	5,00	5,00
Yay Aye Kwin	5,00	4,00	4,00
Average Ward representatives questionnaire	**4.91**	**4.82**	**4.59**

Table 16: ES prioritization by expert consultation and questionnaires to Ward representatives.

Source:Author.

Results from questionnaires to Ward representatives, asked to assign a score from 1 (Very low) to 5 (Very high) to the "Importance for their wellbeing" (Demand) and "Supply satisfaction level" (Supply) of different cultural ES in the UGS that they visit most frequently:

	Importance for wellbeing (DEMAND)						Supply satisfaction (SUPPLY)						No. respondents
UGS Code	Recreation	Aesthetic	Spiritual	Scient. / Tradit. kn.	Education	Community	Recreation	Aesthetic	Spiritual	Scient. / Tradit. kn.	Education	Community	
C1	70	64	72	68	72	69	61	46	57	46	41	57	17
C3	4	4	4	4	4	1	2	4	4	2	1	3	1
G1	7	6	2	5	6	3	5	6	2	5	5	6	2
G2	18	14		11	18	13	16	13		10	7	10	4
G3	8	8		8	8	6	6	6		4	5	8	2
G7	4					4	4					4	1
G18	15	15		11	16	13	13	14		9	7	10	4
G19	5	4	3	4	4	5	1	1	3	1	1	1	1
R3-R7	5	6	13	10	9	10	5	4	13	3	4	10	3
R8	10	8	16	10	10	10	10	8	16	8	8	10	4
R12			4						4				1
S2	10					9	8					9	3

ES not relevant for this UGS

Table 17: Cultural ES prioritization (Total Supply & Demand votes from questionnaires)

Source:Author.

	Importance for wellbeing (DEMAND)						Supply satisfaction (SUPPLY)					
UGS Code	Recreation	Aesthetic	Spiritual	Scient. / Tradit. kn.	Education	Community	Recreation	Aesthetic	Spiritual	Scient. / Tradit. kn.	Education	Community
C1	4,12	3,76	4,24	4,00	4,24	4,06	3,59	2,71	3,35	2,71	2,41	3,35
C3	4,00	4,00	4,00	4,00	4,00	1,00	2,00	4,00	4,00	2,00	1,00	3,00
G1	3,50	3,00	1,00	2,50	3,00	1,50	2,50	3,00	1,00	2,50	2,50	3,00
G2	4,50	3,50		2,75	4,50	3,25	4,00	3,25		2,50	1,75	2,50
G3	4,00	4,00		4,00	4,00	3,00	3,00	3,00		2,00	2,50	4,00
G7	4,00					4,00	4,00					4,00
G18	3,75	3,75		2,75	4,00	3,25	3,25	3,50		2,25	1,75	2,50
G19	5,00	4,00	3,00	4,00	4,00	5,00	1,00	1,00	3,00	1,00	1,00	1,00
R3-R7	1,67	2,00	4,33	3,33	3,00	3,33	1,67	1,33	4,33	1,00	1,33	3,33
R8	2,50	2,00	4,00	2,50	2,50	2,50	2,50	2,00	4,00	2,00	2,00	2,50
R12			4,00						4,00			
S2	3,33					3,00	2,67					3,00
Average	**3,67**	**3,33**	**3,51**	**3,31**	**3,69**	**3,08**	**2,85**	**2,81**	**3,78**	**2,00**	**1,81**	**2,93**

Table 18: Cultural ES prioritization (Supply & Demand Mean values)

Source:Author.

Annex B: ES calculation methods and score tables

B0. SUMMARY OF CLIMATIC DATA FOR TAUNGGYI

Month	Min Temp	Max Temp	PET	Precip.	Humidity	Wind	Reference evapotranspiration (ETo)
	°C	°C	mm/month	mm	%	m/s	mm/day
January	7,3	21,8	63	2	69%	0,9	4.12
February	8,9	24,1	80	2	61%	0,9	5.39
March	12,5	27,3	119	16	53%	1	6.49
April	15,8	28,8	130	50	55%	1,1	7.07
May	17,1	26,5	122	201	72%	1,3	6.09
June	17,3	24,5	102	259	81%	1,5	5.34
July	17,3	23,7	98	296	84%	1,3	5.26
August	17,1	23,3	92	304	85%	1,2	5.08
September	16,7	24,2	89	279	84%	1,2	4.69
October	15,1	23,9	82	224	83%	1,1	4.23
November	12	22,9	64	98	79%	1	3.79
December	8,1	20,5	50	16	80%	0,9	3.61
Average	**24,3**	**13,8**	**1091**	**1747**	**74%**	**1,1**	**5.10**
Source	*FAO climatic database (1961-2010) (FAO 2018a)*						*CROPWAT 8.0 (FAO)*

Table 19: Taunggyi monthly climatic data used for provisioning and regulating ES supply calculation.

Source: Author, 2018.

B1. WATER PROVISION

ES Supply per UGS (underground water recharge)

In this study, a preliminary estimate of groundwater recharge was calculated using a modified version of the Thornthwaite-Mather soil-moisture-balance approach (Thornthwaite and Mather 1957), following the model proposed by the Soil-Water-Balance (SWB) computer code developed by U.S. Geological Survey (USGS 2016):

Recharge = (precip + snowmelt + inflow) – (interception + outflow + ET + Δ soil moisture)

Snowmelt doesn't apply in this climatic zone, and change in soil moisture can be estimated 0 as this research is only studying average yearly values. Besides, due to the lack of data to estimate runoff (digital elevation model at the urban scale), both inflow and outflow are not being considered in this calculation. However, as most UGS in this study are surrounded by urban impervious surfaces, it could be stated that surface runoff inflows would be greater that outflows, hence is more probable that final water recharge volumes in this study are underestimated rather that overestimated.

Hence, the final equation used in this study was: ***Recharge = precip – (interception + ET)***

Thornthwaite Monthly Water-Balance Model (TMWB) was used to estimate the potential evapotranspiration (ET) using local climatic data.

Water interception (the amount of rainfall assumed to be trapped and used by vegetation and evaporated or transpired from plant surfaces) depends on land-cover type and season. Interception storage values were taken from land-cover tables from the SWB database (USGS 2017). Interception values are different for growing and non-growing seasons, but due to the favourable climate in Taunggyi, in which crops grow along all year, only growing season value was applied.

Interception values assigned per land-cover typology:

Land Cover	mm/d
Forest	0.050
Park	0.063
Shrubs	0.063
Grass	0.090
Water	0.00
Paved	0.00

For each UGS, interception values of each land-cover type were multiplied by its correspondent area, to obtain the overall interception capacity per year. Then, interception and potential evapotranspiration were subtracted from precipitation values to get the final groundwater recharge capacity for each UGS (m3 ha-1 year-1) (Table B1).

ES Supply per Ward

Afterwards, water regulation ES supply per ward was calculated by adding the service capacity of each UGS (in m3 year-1) and then normalizing the scores by area (m3 ha-1 year-1) to enable the comparison between the different wards in the city (Table B2).

ES Demand per Ward (water consumption)

The demand for water provision (m3 ha-1 year-1) was calculated by multiplying the average water consumption per capita by the population in each ward. In the absence of local data, national average was used, provided by the Myanmar Ministry of Construction. This value was estimated 40 gallons per day and person (0.15 m3 day-1) (Table B2).

UGS Code	UGS Area (m2)	Forest (m2)	Grass (m2)	Shrub/Park (m2)	Paved (m2)	Water (m2)	Interception capacity per UGS (m3/year)	Groundwater recharge per UGS (m3/year)	Groundwater recharge (m3 ha-1 year-1)
C01	4147785	4147785	0	0	0	0	27790,16	2693156,80	6493,00
C02	3228266	502329	1614133	968480	0	143324	30943,07	2086799,43	6464,15
C03	5113154	5113154	0	0	0	0	34258,13	3319970,89	6493,00
G01	34002	19556	0	0	1700	12746	131,02	21059,02	6193,47
G02	7787	779	4672	1557	779	0	74,61	4522,84	5808,19
G03	46565	32596	13970	0	0	0	386,86	30159,78	6476,92
G04	155813	77907	46744	31163	0	0	1346,69	100866,64	6473,57
G05	70862	53147	7086	7086	3543	0	500,89	43660,31	6161,32
G06	108553	0	97698	0	10855	0	1178,23	62911,46	5795,46
G07	35829	10749	7166	14332	3583	0	278,46	20874,98	5826,28
G08	36767	18384	7353	11030	0	0	304,23	23814,92	6477,26
G09	20037	18033	0	2004	0	0	137,60	13006,67	6491,33
G10	16587	14928	0	1659	0	0	113,91	10767,16	6491,33
G11	15612	9737	0	1561	0	4314	78,31	10163,16	6509,84
G12	155689	7784	62276	77845	15569	0	1455,15	90463,64	5810,54
G13	161142	80571	32228	48343	0	0	1333,37	104375,78	6477,26
G14	63494	50795	12699	6349	0	0	546,65	41105,41	6473,91
G15	7385	6647	0	739	0	0	50,72	4793,84	6491,33
G16	14755	14755	0	0	0	0	98,86	9580,42	6493,00
G17	147121	132409	14712	0	0	0	1064,57	95446,81	6487,64
G18	55989	50390	0	0	5599	0	337,61	32718,29	5843,70
G19	336240	50436	0	268992	16812	0	2590,73	206954,04	6154,95
G20	97573	40128	29272	9757	0	18416	703,59	63304,30	6487,89
M01	2540473	254047	762142	762142	762142	0	17276,49	1149308,71	4524,00
M02	1463244	146324	877946	292649	146324	0	14019,34	849879,92	5808,19

M03	2901613	1450807	580323	870484	0	0	24009,40	1879448,73	6477,26
M04	600119	120024	180036	180036	120024	0	4483,19	310459,26	5173,30
M05	46434	23217	13930	0	9287	0	323,55	24045,01	5178,32
R01	21084	15813	0	4217	1054	0	141,26	12998,29	6165,00
R02	194891	97446	19489	38978	38978	0	1214,37	101064,43	5185,69
R03	69471	69471	0	0	0	0	465,46	45107,52	6493,00
R04	101359	91223	10136	0	0	0	733,43	65758,07	6487,64
R05	84698	16940	25409	25409	16940	0	632,74	43816,77	5173,30
R06	43751	41563	0	0	2188	0	278,48	26987,15	6168,35
R07	45412	40871	0	0	4541	0	273,83	26537,41	5843,70
R08	41081	24649	0	16432	0	0	302,77	26646,37	6486,30
R09	71622	21487	14324	21487	14324	0	496,66	37090,56	5178,66
R10	762664	76266	228799	305066	152533	0	5825,23	394420,84	5171,62
R11	89361	67021	17872	0	4468	0	664,58	55025,20	6157,63
R12	23396	18717	4679	0	0	0	181,83	15165,94	6482,28
R13	16665	1667	5000	9999	0	0	155,20	10777,04	6466,87
S01	350152	175076	140061	35015	0	0	3155,39	226544,32	6469,89
S02	39367	0	39367	0	0	0	474,77	25349,99	6439,40

Table 20: Calculation table for Water provision Supply per UGS

Source: Author, 2018.

Ward	Water provision Supply			Water provision Demand		
	Area (m2)	Total groundwater recharge (m3/year)	Groundwater recharge (m3 ha-1 year-1)	Population	Total Water demand (m3 year-1)	Water demand (m3 ha-1 year-1)
Chan Myae Ther Si	35,01	0,00	0,00	6510	359788,25	10276,46
Chan Ther	36,91	42297,97	1145,84	3927	217033,56	5879,36
Haw Kone	8,33	0,00	0,00	1307	72233,98	8670,09
Hzay Paing	15,22	0,00	0,00	1458	80579,30	5293,36
Kan Kyi	174,92	36096,26	206,36	2668	147452,39	842,98
Kan Out	20,26	0,00	0,00	2309	127611,53	6299,91
Kan Shae	23,96	0,00	0,00	2862	158174,19	6600,38
Kan Ther	67,83	104550,54	1541,26	5779	319388,06	4708,34
Kyaung Gyi Su	846,42	1079092,63	1274,89	22820	1261193,21	1490,04
Lan Ma Taw	14,45	0,00	0,00	1786	98706,88	6829,41
Mingalar Oo	52,70	0,00	0,00	5990	331049,40	6282,23
Myo Ma	21,47	0,00	0,00	4469	246988,28	11504,41
Nyaung Phyu	93,30	90463,64	969,60	15397	850946,18	9120,51
Nyaung Shwe Haw Kone	24,85	21059,02	847,44	2219	122637,50	4935,07
Phayar Phyu	891,68	534924,62	599,90	15440	853322,67	956,98
Pyi Taw Ther	29,33	0,00	0,00	3272	180833,66	6165,02
Sat Sen Htun	461,37	1228937,35	2663,64	10991	607439,73	1316,59
Sein Pann	33,10	0,00	0,00	7568	418260,75	12634,83
Shwe Taung	27,31	0,00	0,00	9239	510611,92	18696,20
Thit Taw	149,10	110723,98	742,62	6327	349674,39	2345,24
Yandanar Thiri	41,05	0,00	0,00	9418	520504,72	12678,79
Yay Aye Kwin	160,93	46403,09	288,34	11549	638278,72	3966,14
Periurban n. a. 1	696,05	4518742,40	6492,02	0	0,00	0,00
Periurban n. a. 2	518,67	2724209,37	5252,27	0	0,00	0,00
Periurban n. a. 3	511,32	3319970,89	6493,00	0	0,00	0,00
TOTAL		**13857471,75**			**8472709,28**	

Table 21: Calculation table for Water provision Supply and Demand per Ward

Source: Author, 2018.

B2. URBAN TEMPERATURE REGULATION

ES Supply per UGS (ºC temperature reduction)

The supply of the ES Urban temperature regulation was quantified using the method proposed by Zardo et al. (2017), which uses vegetation shading and evapotranspiration indicators to estimate microclimate regulation by the urban green spaces. The assessment of these values assesses are based on three properties of green areas: soil cover, canopy coverage and size.

ETA = Kc*ETo (FAO, 1998)

Shading = % tree canopy coverage

The evapotranspiration coefficient (Kc) for each green space was obtained from the coefficients assigned by InVEST to the correspondent Land Use classes (evergreen forest, mixed forest, shrub, grass, water, paved surfaces) (Natural Capital Project 2015). Reference evapotranspiration (ETo) for Taunggyi was obtained through the Penman-Monteith equation using the open source software CROPWAT 8.0 developed by the Land and Water Development Division of FAO.

Evapotranspiration coefficient (Kc) values assigned per land-cover typology:

Land Cover	Kc
Forest	1
Shrubs	0,43
Grass	0,65
Water	1
Paved	0.2

For each UGS, ETA value was obtained by summing the ETA of each Land Use class weighed by the proportion of its area over the total. Shading score was calculated by the percentage of tree canopy coverage for each UGS. Afterwards, both ETA and shading values were converted into 1-5 range scores.

According to previous empirical studies, the relative contribution of shading and evapotranspiration to the overall cooling capacity is determined by the size of the green space (Chang et al., 2007; Bowler et al., 2010; Cao et al., 2010, Shashua-Bar and Hoffman, 2000), so the final score calculation was made through a weighted summation of both factors depending on their size: ETA was assigned a weight of 0.2 and shading of 0.8 in areas smaller than two hectares; while in areas larger than two hectares the weights were 0.6 and 0.4 respectively.

Finally, cooling capacity scores were associated to expected temperature changes (minimum and maximum values of temperature variation) according to the results from studies in similar climatic regions through literature review (Padmanabhamurty 1990). The maximum and minimum cooling values (2.5ºC and 1ºC) were assigned to the highest and lowest cooling capacity scores (5 and 1, respectively), with the rest of the values (4, 3, 2) calculated as decreasing linearly (Table B3).

UGS Code	Forest/ Water (%)	Grass (%)	Shrub (%)	Paved (%)	ETA (mm/day)	ETA score (1-5)	Shading score (%)	Shading score (1-5)	ETA weight	Shading weight	Cooling capacity (1-5)	Cooling capacity (ºC)
C01	1	-	-	-	5,10	5,0	1	5,0	0,6	0,4	5,00	2,50
C02	0,2	0,5	0,3	-	3,34	3,3	0,2	1,0	0,6	0,4	2,36	1,52
C03	1	-	-	-	5,10	5,0	1	5,0	0,6	0,4	5,00	2,50
G01	0,95	-	-	0,05	4,90	4,8	0,95	4,8	0,6	0,4	4,78	2,42
G02	0,1	0,6	0,2	0,1	3,04	3,0	0,1	0,5	0,2	0,8	1,00	1,02
G03	0,7	0,3	-	-	4,56	4,5	0,7	3,5	0,6	0,4	4,09	2,16
G04	0,5	0,3	0,2	-	3,98	3,9	0,5	2,5	0,6	0,4	3,34	1,89
G05	0,75	0,1	0,1	0,05	4,43	4,3	0,75	3,8	0,6	0,4	4,10	2,17
G06	-	0,9	-	0,1	3,09	3,0	0	0,0	0,6	0,4	1,82	1,32
G07	0,3	0,2	0,4	0,1	3,17	3,1	0,3	1,5	0,6	0,4	2,47	1,56
G08	0,5	0,2	0,3	-	3,87	3,8	0,5	2,5	0,6	0,4	3,28	1,86
G09	0,9	-	0,1	-	4,81	4,7	0,9	4,5	0,6	0,4	4,63	2,36
G10	0,9	-	0,1	-	4,81	4,7	0,9	4,5	0,2	0,8	4,54	2,33
G11	0,9	-	0,1	-	4,81	4,7	0,9	4,5	0,2	0,8	4,54	2,33
G12	0,05	0,2	0,65	0,1	2,45	2,4	0,05	0,3	0,6	0,4	1,54	1,22
G13	0,5	0,2	0,3	-	3,87	3,8	0,5	2,5	0,6	0,4	3,28	1,86
G14	0,8	0,1	0,1	-	4,63	4,5	0,8	4,0	0,6	0,4	4,32	2,25
G15	0,9	-	0,1	-	4,81	4,7	0,9	4,5	0,2	0,8	4,54	2,33
G16	1	-	-	-	5,10	5,0	1	5,0	0,2	0,8	5,00	2,50
G17	0,9	0,1	-	-	4,92	4,8	0,9	4,5	0,6	0,4	4,70	2,39
G18	0,9	-	-	0,1	4,69	4,6	0,9	4,5	0,6	0,4	4,56	2,34
G19	0,15	-	0,8	0,05	2,57	2,5	0,15	0,8	0,6	0,4	1,81	1,32
G20	0,6	0,3	0,1	-	4,27	4,2	0,6	3,0	0,6	0,4	3,71	2,02
M01	0,1	0,3	0,3	0,3	2,47	2,4	0,1	0,5	0,6	0,4	1,65	1,26

M02	0,1	0,6	0,2	0,1	3,04	3,0	0,1	0,5	0,6	0,4	1,99	1,38
M03	0,5	0,2	0,3	-	3,87	3,8	0,5	2,5	0,6	0,4	3,28	1,86
M04	0,2	0,3	0,3	0,2	2,88	2,8	0,2	1,0	0,6	0,4	2,09	1,42
M05	0,5	0,3	-	0,2	3,75	3,7	0,5	2,5	0,6	0,4	3,21	1,83
R01	0,75	-	0,2	0,05	4,31	4,2	0,75	3,8	0,6	0,4	4,04	2,14
R02	0,5	0,1	0,2	0,2	3,52	3,5	0,5	2,5	0,6	0,4	3,07	1,79
R03	1	-	-	-	5,10	5,0	1	5,0	0,6	0,4	5,00	2,50
R04	0,9	0,1	-	-	4,92	4,8	0,9	4,5	0,6	0,4	4,70	2,39
R05	0,2	0,3	0,3	0,2	2,88	2,8	0,2	1,0	0,6	0,4	2,09	1,42
R06	0,95	-	-	0,05	4,90	4,8	0,95	4,8	0,6	0,4	4,78	2,42
R07	0,9	-	-	0,1	4,69	4,6	0,9	4,5	0,6	0,4	4,56	2,34
R08	0,6	-	0,4	-	3,94	3,9	0,6	3,0	0,6	0,4	3,52	1,95
R09	0,3	0,2	0,3	0,2	3,05	3,0	0,3	1,5	0,6	0,4	2,40	1,54
R10	0,1	0,3	0,4	0,2	2,59	2,5	0,1	0,5	0,6	0,4	1,72	1,28
R11	0,75	0,2	-	0,05	4,54	4,5	0,75	3,8	0,6	0,4	4,17	2,19
R12	0,8	0,2	-	-	4,74	4,7	0,8	4,0	0,6	0,4	4,39	2,27
R13	0,1	0,3	0,6	-	2,82	2,8	0,1	0,5	0,2	0,8	0,95	1,00
S01	0,5	0,4	0,1	-	4,10	4,0	0,5	2,5	0,6	0,4	3,41	1,91
S02	-	1	-	-	3,32	3,3	0	0,0	0,6	0,4	1,95	1,37

Table 22: Calculation table for Urban temperature regulation Supply per UGS

Source: Author, 2018.

ES Supply per Ward

In order to apply the temperature regulation effect to each ward, estimations from previous observational studies were taken into account. Although the distance to which UGS' cooling effect expands over the surrounding urban area depends on multiple factors as topography, urban morphology or wind patterns, and it also changes throughout the day and the different seasons in a year, there is a general agreement that its impact is generally proportional to the scale of the green area under study. According to revised literature (Jauregui 1990; Saito et al. 1990; Ca et al. 1998; Nowak and Heisler 2010), in this study cooling bands from UGS were estimated to extend 1 km around parks over 300 ha, 600 m around parks between 300 and 50ha, 300 m around parks between 50 and 2 ha, and100 m around parks under 2 ha.

To obtain an average temperature regulation supply score per ward, the temperature reduction (ºC) by each UGS was multiplied by its area plus its effect area, and then divided by the total area of the ward where it is located (Table B4).

ES Demand per Ward (temperature increase with population density)

Due to data limitations (absence of information on thermal behaviour in different areas of the city), the demand for local climate regulation was measured through the population density in each ward. This responds to the fact that, as multiple studies state (Verdonck et al. 2018; Coutts et al. 2007), densely built zones are more prone to suffer the Urban Heat Island Effect; and, at the same time, the proportion of vulnerable groups (elderly, children, people with diseases, low-income households, etc.) exposed to heat risk is also higher in dense areas. According to previous studies in similar contexts as Delhi in India (Mallick and Rahman 2012), population density affects most in areas below 20.000 p/km2 density, which is the case of the wards in Taunggyi. An average of 1ºC temperature increase was estimated for every 80 p/ha increase in urban density in all wards except for the ones below 40 p/ha where UHI effect was considered irrelevant. (Table B4).

	Urban temperature regulation Supply		Urban temperature regulation Demand	
Ward	Area (m2)	Cooling supply (ºC)	Population density (person/ha)	Cooling demand (ºC)
Chan Myae Ther Si	35,01	0,00	185,94	1,32
Chan Ther	36,91	1,56	106,38	0,33
Haw Kone	8,33	0,03	156,88	0,96
Hzay Paing	15,22	0,02	95,78	0,20
Kan Kyi	174,92	0,43	15,25	0,00
Kan Out	20,26	0,01	113,99	0,42
Kan Shae	23,96	1,31	119,43	0,49
Kan Ther	67,83	1,16	85,19	0,06
Kyaung Gyi Su	846,42	0,52	26,96	0,00
Lan Ma Taw	14,45	0,82	123,57	0,54
Mingalar Oo	52,70	1,44	113,67	0,42
Myo Ma	21,47	0,79	208,16	1,60
Nyaung Phyu	93,30	0,44	165,03	1,06
Nyaung Shwe Haw Kone	24,85	0,39	89,30	0,12
Phayar Phyu	891,68	0,65	17,32	0,00
Pyi Taw Ther	29,33	0,38	111,55	0,39
Sat Sen Htun	461,37	1,01	23,82	0,00
Sein Pann	33,10	0,00	228,61	1,86
Shwe Taung	27,31	0,00	338,29	3,23
Thit Taw	149,10	1,60	42,43	0,00
Yandanar Thiri	41,05	0,00	229,41	1,87
Yay Aye Kwin	160,93	1,93	71,76	0,00
Periurban natural area 1	696,05	2,24	0,00	0,00
Periurban natural area 2	518,67	1,24	0,00	0,00
Periurban natural area 3	511,32	2,50	0,00	0,00

Table 23: Calculation table for Urban temperature regulation Supply and Demand per Ward

Source: Author, 2018.

B3. GLOBAL CLIMATE REGULATION

ES Supply per UGS (Carbon sequestration)

The ES supply of global climate regulation was estimated through the average annual carbon sequestration values (t C/ha) assigned per unit of tree cover area in each green space, based on the assessment carried out by Nowak et al. (2013) for 28 cities in the United States. As tree growth (and thus CO_2 sequestration) varies depending on the local environmental conditions, standardized values from Nowak's study were adjusted as in previous studies (Baró et al. 2015) using the length of the growing season as a proxy, following the formula:

$$C' = C * GS / 174$$

Where C′ = average net carbon sequestration rate (kg C m^{-2} tree cover year); C = US average net carbon sequestration rate (2.05 kg C m^{-2} tree cover year) from Nowak et al. (2013); and GS = length of the growing season (days). As Taunggyi has a humid subtropical climate and according to indications from the Myanmar Ministry of Construction it was estimated that the growing season covers the whole year (365 days).

Finally, carbon sequestration rates were converted to carbon dioxide (CO_2) using the conversion factor 1 g C = 3.67 g CO_2.

$$C' = C * GS / 174 = 2.05 * 365 / 174 = 4.30 \text{ t C ha}^{-1} \text{ year}^{-1} = 15.77 \text{ t } CO_2 \text{ ha}^{-1} \text{ year}^{-1}$$

This value was multiplied by the tree cover area for each UGS in order to get the final sequestration capacity level for each of them (Table B5).

ES Supply per Ward

Global climate regulation ES per Ward was estimated by simply adding the values from the forested UGS within their boundaries and then normalizing the scores by area (tCO_2 ha^{-1} $year^{-1}$) to enable the comparison between the different wards (Table B6).

ES Demand per Ward (Carbon emissions)

The demand indicator for the ES global climate regulation was estimated on the basis of annual CO_2 emissions (metric tons per capita) as suggested by Burkhard et al. (2014). In the absence of local data, national average value was used from the World Bank database (https://data.worldbank.org/country/myanmar), and then multiplied by the population of each ward and divided by its area. The last value recorded by the World Bank was used, which corresponds to 0.417 metric tons per capita in December 2014 (Table B6).

UGS Code	UGS Area (ha)	Tree cover (ha)	CO2 sequestr. per UGS (t C year-1)	CO2 sequestration (t CO2 ha-1 year-1)
C01	414,78	414,78	6540,11	15,77
C02	322,83	50,23	792,06	2,45
C03	511,32	511,32	8062,28	15,77
G01	3,40	1,96	30,84	9,07
G02	0,78	0,08	1,23	1,58
G03	4,66	3,26	51,40	11,04
G04	15,58	7,79	122,84	7,88
G05	7,09	5,31	83,80	11,83
G06	10,86	0,00	0,00	0,00
G07	3,58	1,07	16,95	4,73
G08	3,68	1,84	28,99	7,88
G09	2,00	1,80	28,43	14,19
G10	1,66	1,49	23,54	14,19
G11	1,56	0,97	15,35	9,83
G12	15,57	0,78	12,27	0,79
G13	16,11	8,06	127,04	7,88
G14	6,35	5,08	80,09	12,61
G15	0,74	0,66	10,48	14,19
G16	1,48	1,48	23,27	15,77
G17	14,71	13,24	208,78	14,19
G18	5,60	5,04	79,45	14,19
G19	33,62	5,04	79,53	2,37
G20	9,76	4,01	63,27	6,48
M01	254,05	25,40	400,57	1,58
M02	146,32	14,63	230,72	1,58
M03	290,16	145,08	2287,59	7,88
M04	60,01	12,00	189,25	3,15
M05	4,64	2,32	36,61	7,88
R01	2,11	1,58	24,93	11,83
R02	19,49	9,74	153,65	7,88
R03	6,95	6,95	109,54	15,77
R04	10,14	9,12	143,84	14,19
R05	8,47	1,69	26,71	3,15
R06	4,38	4,16	65,54	14,98
R07	4,54	4,09	64,44	14,19
R08	4,11	2,46	38,87	9,46
R09	7,16	2,15	33,88	4,73
R10	76,27	7,63	120,25	1,58
R11	8,94	6,70	105,68	11,83
R12	2,34	1,87	29,51	12,61
R13	1,67	0,17	2,63	1,58
S01	35,02	17,51	276,05	7,88
S02	3,94	0,00	0,00	0,00

Table 24: Calculation table for Global climate regulation Supply per UGS

Source: Author, 2018.

	Global climate regulation Supply			Global climate regulation Demand		
Ward	Area (m2)	Total CO2 sequestration (t C year-1)	CO2 sequestration (t CO2 ha-1 year-1)	Population	Total CO2 emissions (t CO2 year-1)	CO2 emissions (t CO2 ha-1 year-1)
Chan Myae Ther Si	35,01	0,00	0,00	6510	2734,20	78,10
Chan Ther	36,91	102,72	2,78	3927	1649,34	44,68
Haw Kone	8,33	0,00	0,00	1307	548,94	65,89
Hzay Paing	15,22	0,00	0,00	1458	612,36	40,23
Kan Kyi	174,92	68,40	0,39	2668	1120,56	6,41
Kan Out	20,26	0,00	0,00	2309	969,78	47,88
Kan Shae	23,96	0,00	0,00	2862	1202,04	50,16
Kan Ther	67,83	238,04	3,51	5779	2427,18	35,78
Kyaung Gyi Su	846,42	1006,57	1,19	22820	9584,40	11,32
Lan Ma Taw	14,45	0,00	0,00	1786	750,12	51,90
Mingalar Oo	52,70	0,00	0,00	5990	2515,80	47,74
Myo Ma	21,47	0,00	0,00	4469	1876,98	87,43
Nyaung Phyu	93,30	12,27	0,13	15397	6466,74	69,31
Nyaung Shwe Haw Kone	24,85	30,84	1,24	2219	931,98	37,50
Phayar Phyu	891,68	578,91	0,65	15440	6484,80	7,27
Pyi Taw Ther	29,33	0,00	0,00	3272	1374,24	46,85
Sat Sen Htun	461,37	587,04	1,27	10991	4616,22	10,01
Sein Pann	33,10	0,00	0,00	7568	3178,56	96,02
Shwe Taung	27,31	0,00	0,00	9239	3880,38	142,08
Thit Taw	149,10	128,10	0,86	6327	2657,34	17,82
Yandanar Thiri	41,05	0,00	0,00	9418	3955,56	96,35
Yay Aye Kwin	160,93	112,69	0,70	11549	4850,58	30,14
Periurban n. a. 1	696,05	8696,90	12,49	0	0,00	0,00
Periurban n. a. 2	518,67	965,10	1,86	0	0,00	0,00
Periurban n. a. 3	511,32	8062,28	15,77	0	0,00	0,00
TOTAL		**20589,85**			**64388,10**	

Table 25: Calculation table for Global climate regulation Supply and Demand per Ward

Source: Author, 2018.

A4. CULTURAL VALUES

ES Supply per UGS

Cultural ES Supply was measured through the “Supply satisfaction” value assigned by questionnaire respondents to the UGS they commonly visit or know better, from 1 (very dissatisfied) to 5 (very satisfied).

First, cultural ES supply per UGS was estimated by weighting their mean scores with the total votes received in the questionnaires. As no UGS received the maximum supply score (5, very high), values were refactored in a range from 1 to 3.6 for “Recreation”, which was the maximum value received by UGS C1, the peri-urban forest in Mya Sein Mountain. In the case of “Education” ES, the maximum was 2.4 (Table B7). UGS which were not mentioned by any respondent were excluded.

	Recreation Supply per UGS			Education Supply per UGS		
UGS Code	Total votes	Mean score (1-5)	Standardized score (1=1; 61=3,6)	Total votes	Mean score	Standardized score (1=1; 41=2,4)
C01	61	3,6	3,6	41	2,4	2,4
C03	2	2,0	1,0	1	1,0	1,0
G01	5	2,5	1,2	5	2,5	1,1
G02	16	4,0	1,6	7	1,8	1,2
G03	6	3,0	1,2	5	2,5	1,1
G04	4	4,0	1,1	-	-	-
G18	13	3,3	1,5	7	1,8	1,2
G19	1	1,0	1,0	1	1,0	1,0
R03	5	1,7	1,67	4	1,3	1,1
R04	5	1,7	1,67	4	1,3	1,1
R05	5	1,7	1,67	4	1,3	1,1
R06	5	1,7	1,67	4	1,3	1,1
R07	5	1,7	1,67	4	1,3	1,1
R08	10	2,5	2,50	8	2,0	1,2
S02	8	2,7	2,67	-	-	-

Table 26: Calculation table for Recreation and Education Supply per UGS

Source: Author, 2018.

ES Supply per Ward

For the calculation of Cultural ES supply per Ward, results from questionnaires of UGS supply scores were combined with data from national standards for the proportion of area that should be assigned to green green public space in urban areas.

According to the recently published Guidelines for Urban Planning in Myanmar (UN-Habitat 2016), 15-20% of urban land should be allocated for other open public spaces. Since this thesis only studies vegetated areas (UGS), 10% was stablished as the minimum threshold for each ward:

- If the summed area of UGS was equal or above 10% of the ward area, ES Supply score per ward was calculated by the weighted addition of the scores from the UGS within their boundaries.
- If the summed area of UGS was below 10% of the ward area, the average ES Supply score of the UGS was reduced proportionally to the % of area below 10% (eg. if the average recreation supply value from the UGS in a ward was 4, but the UGS area was 2.5% of ward area, the ward recreation supply score was calculated as 4*2.5/10=1%).

Finally, wards in which no UGS were mentioned for cultural ES supply were scored 1 (very low). (Table B8).

	Recreation Supply			Education Supply		
Ward	Recreation area per ward (%)	Avg. recreation supply by UGS (1-5)	Recreation supply per Ward (1-5)	Education area per ward (%)	Avg. Education supply by UGS (1-5)	Education supply per Ward (1-5)
Chan Myae Ther Si	0%		1,00	0%		1,00
Chan Ther	19%	1,7	1,67	19%	1,1	1,11
Haw Kone	0%		1,00	0%		1,00
Hzay Paing	0%		1,00	0%		1,00
Kan Kyi	0%		1,00	0%		1,00
Kan Out	0%		1,00	0%		1,00
Kan Shae	0%		1,00	0%		1,00
Kan Ther	24%	1,7	1,67	24%	1,1	1,11
Kyaung Gyi Su	3%	1,4	1,00	1%	1,1	1,00
Lan Ma Taw	0%		1,00	0%		1,00
Mingalar Oo	0%		1,00	0%		1,00
Myo Ma	0%		1,00	0%		1,00
Nyaung Phyu	0%		1,00	0%		1,00
Nyaung Shwe Haw Kone	14%	1,2	1,17	14%	1,1	1,14
Phayar Phyu	0%		1,00	0%		1,00
Pyi Taw Ther	0%		1,00	0%		1,00
Sat Sen Htun	1%	1,5	1,00	1%	1,2	1,00
Sein Pann	0%		1,00	0%		1,00
Shwe Taung	0%		1,00	0%		1,00
Thit Taw	9%	2,1	1,86	6%	1,2	1,00
Yandanar Thiri	0%		1,00	0%		1,00
Yay Aye Kwin	5%	3,6	1,71	5%	2,4	1,15
Periurban n. a. 1	58%	3,6	3,59	58%	2,4	2,41
Periurban n. a. 2	62%		1,00	62%		1,00
Periurban n. a. 3	100%	1,0	1,04	100%	1,0	1,00

Table 27: Calculation table for Recreation and Education Supply per Ward

Source: Author, 2018.

Demand per ward

Demand for cultural ES in each ward was estimated by the average importance for their wellbeing stated by the correspondent ward representative, from 1 (very unimportant) to 5 (very important). Besides, ward population density was also taken into account, refactoring the values to a 3-5 scale, as all the urban wards show a relatively high density (except for the peri-urban areas, which had no population). Both factors were assigned the same weigh for calculating the final ES Demand scores (Table B9).

Ward	Pop. Density (person/ha)	Refactored Pop. Dens. (3-5)	Recreation Demand		Education Demand	
			Questionnaire Recreation demand (1-5)	Weighted Recreation demand (1-5)	Questionnaire Education demand (1-5)	Weighted Education demand (1-5)
Chan Myae Ther	185,9	4	5,00	5	5,00	5
Chan Ther	106,4	4	5,00	4	4,00	4
Haw Kone	156,9	4	4,00	4	4,00	4
Hzay Paing	95,8	3	4,00	4	4,00	4
Kan Kyi	15,3	3	4,00	4	5,00	4
Kan Out	114,0	4	4,00	4	4,00	4
Kan Shae	119,4	4	4,00	4	5,00	4
Kan Ther	85,2	3	4,00	4	5,00	4
Kyaung Gyi Su	27,0	3	4,00	4	4,00	4
Lan Ma Taw	123,6	4	4,33	4	4,00	4
Mingalar Oo	113,7	4	4,00	4	4,00	4
Myo Ma	208,2	4	5,00	5	4,00	4
Nyaung Phyu	165,0	4	4,00	4	4,00	4
Nyaung Shwe	89,3	3	4,00	4	4,00	4
Phayar Phyu	17,3	3	3,00	3	4,00	4
Pyi Taw Ther	111,5	4	4,00	4	4,00	4
Sat Sen Htun	23,8	3	4,00	4	4,00	4
Sein Pann	228,6	4	5,00	5	5,00	5
Shwe Taung	338,3	5	3,00	4	4,00	5
Thit Taw	42,4	3	4,00	4	4,00	4
Yandanar Thiri	229,4	4	4,00	4	4,00	4
Yay Aye Kwin	71,8	3	4,00	4	4,00	4
Periurban n. a. 1	0	0	4,12	2	4,29	2
Periurban n. a. 2	0	0	-	1	-	1
Periurban n. a. 3	0	0	4,00	2	5,00	3

Table 28: Calculation table for Recreation and Education Demand per Ward

Source: Author, 2018.

Annex C: Statistical results (SPSS Software)

Inferential statistics to identify potential influencing factors on UGS ES supply levels:

LINEAR REGRESSION ANALYSIS (UGS Area)

UGS Area and Water provision:

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6100,152	89,283		68,324	,000
	Area Area in ha	,042	,689	,010	,061	,952

a. Dependent Variable: Water_provision Water provision

UGS Area and Urban temperature regulation:

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1,912	,079		24,121	,000
	Area Area in ha	9,079E-005	,001	,023	,148	,883

a. Dependent Variable: Temp_reg Urban temperature regulation

UGS Area and Global Climate regulation:

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8,511	,897		9,483	,000
	Area Area in ha	,001	,007	,023	,150	,882

a. Dependent Variable: CO2_Sequestr Global Climate regulation

UGS Area and Recreation:

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1,640	,200		8,210	,000
	Area Area in ha	,001	,001	,267	1,001	,335

a. Dependent Variable: Recr_Sup Recreation Supply satisfaction

UGS Area and Education:

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1,144	,102		11,243	,000
	Area Area in ha	,001	,001	,486	1,845	,092

a. Dependent Variable: Educ_Sup Education Supply satisfaction

T-TEST (UGS Accessibility)

UGS Accessibility and Water provision:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Water provision	Equal variances assumed	4,463	,041	-1,854	41	,071	-354,14317	191,00744	-739,89053	31,60419
	Equal variances not assumed			-1,400	9,634	,193	-354,14317	252,98917	-920,75282	212,46648

UGS Area and Urban temperature regulation:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Urban temperature regulation	Equal variances assumed	1,521	,225	-1,524	41	,135	-,26176	,17179	-,60870	,08517
	Equal variances not assumed			-1,776	15,976	,095	-,26176	,14739	-,57426	,05073

UGS Area and Global Climate regulation:

Independent Samples Test

	Levene's Test for Equality of Variances	t-test for Equality of Means

		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Global Climate regulation	Equal variances assumed	,932	,340	-1,946	41	,059	-3,72232	1,91301	-7,58572	,14108
	Equal variances not assumed			-2,139	14,430	,050	-3,72232	1,74044	-7,44478	,00014

UGS Area and Recreation:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Recreation Supply satisfaction	Equal variances assumed	,136	,718	,792	13	,442	,42962	,54229	-,74193	1,60116
	Equal variances not assumed			,707	1,243	,588	,42962	,60734	-4,49301	5,35224

UGS Area and Education:

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper

Education Supply satisfaction	Equal variances assumed	.	.	-,038	11	,970	-,01500	,39533	-,88511	,85511
	Equal variances not assumed			.	.	.	-,01500	.	.	.

ANOVA TEST (Land Use and Land Cover)

LEVENE'S TEST: Land Use

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Water_provision Water provision	6,827	6	36	,000
Temp_reg Urban temperature regulation	2,578	6	36	,035
CO2_Sequestr Global Climate regulation	1,336	6	36	,267
Recr_Sup Recreation Supply satisfaction	31,261[a]	2	9	,000
Educ_Sup Education Supply satisfaction	384,059[b]	2	8	,000

a. Groups with only one case are ignored in computing the test of homogeneity of variance for Recr_Sup Recreation Supply satisfaction.

b. Groups with only one case are ignored in computing the test of homogeneity of variance for Educ_Sup Education Supply satisfaction.

LEVENE'S TEST: Land Cover

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Water_provision Water provision	2,795	6	36	,025
Temp_reg Urban temperature regulation	2,666	6	36	,030
CO2_Sequestr Global Climate regulation	1,991	6	36	,093
Recr_Sup Recreation Supply satisfaction	.[a,b]	0	.	.
Educ_Sup Education Supply satisfaction	.[c,d]	0	.	.

a. Groups with only one case are ignored in computing the test of homogeneity of variance for Recr_Sup Recreation Supply satisfaction.

b. Test of homogeneity of variances cannot be performed for Recr_Sup Recreation Supply satisfaction because only one group has a computed variance.

c. Groups with only one case are ignored in computing the test of homogeneity of variance for Educ_Sup Education Supply satisfaction.

d. Test of homogeneity of variances cannot be performed for Educ_Sup Education Supply satisfaction because only one group has a computed variance.

ONE-WAY ANOVA: Land Use and Global Climate regulation

ANOVA

CO2_Sequestr Global Climate regulation

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	201,502	6	33,584	1,253	,303
Within Groups	964,851	36	26,801		
Total	1166,353	42			

ONE-WAY ANOVA: Land Cover and Global Climate regulation

ANOVA

CO2_Sequestr Global Climate regulation

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1067,606	6	177,934	64,869	,000
Within Groups	98,747	36	2,743		
Total	1166,353	42			

TURKEY POST-HOC TEST: Land Cover and Global Climate regulation

CO2_Sequestr Global Climate regulation

Tukey B

LandCover_2 Land Cover	N	Subset for alpha = 0.05		
		1	2	3
6 Grassland	3	,5267		
4 Shrubland	3	1,5800		
5 Mosaic herbaceous	2	2,0150		
7 Paved-Mixed vegetation	5	2,8380		
3 Mosaic Tree-Grass	4		7,5300	
2 Mosaic Tree-Shrub	6		7,6183	
1 Forest	20			13,4020

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,818.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

KRUSKAL-WALLIS TEST (Land Use and Land Cover)

KRUSKAL-WALLIS TEST: Land Use

Test Statistics[a,b]

	Water provision	Urban temperature regulation	Recreation Supply satisfaction	Education Supply satisfaction
Chi-Square	14,382	7,189	8,711	4,284
df	6	6	5	4
Asymp. Sig.	,026	,304	,121	,369

a. Kruskal Wallis Test

b. Grouping Variable: Land Use

Ranks

	Land Use	N	Mean Rank
Water provision	1 Conservation	3	34,33
	2 City Park	4	12,75
	3 Neighbourhood forest	3	40,17
	4 Institutional	9	16,89
	5 Religious	13	18,85
	6 Sportive	2	22,50
	7 Vacant	9	25,50
	Total	43	

KRUSKAL-WALLIS TEST: Land Cover

Test Statistics[a,b]

	Water_provision Water provision	Temp_reg Urban temperature regulation	Recr_Sup Recreation Supply satisfaction	Educ_Sup Education Supply satisfaction
Chi-Square	20,563	36,591	7,259	5,040
df	6	6	6	4
Asymp. Sig.	,002	,000	,298	,283

a. Kruskal Wallis Test

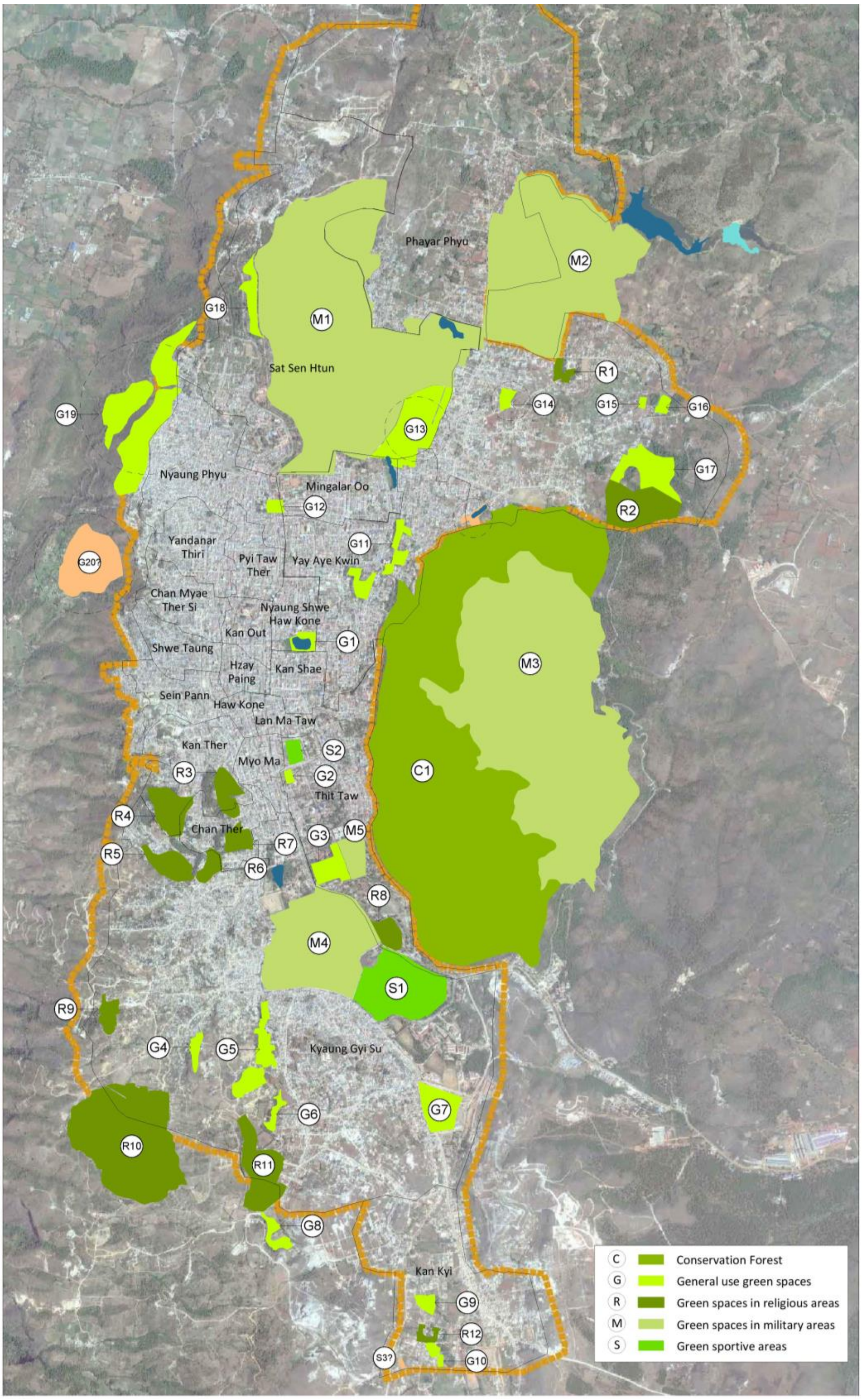
b. Grouping Variable: Land Cover

Ranks

	Land Cover	N	Mean Rank
Water provision	1 Forest	20	29,20
	2 Mosaic Tree-Shrub	6	23,00
	3 Mosaic Tree-Grass	4	22,25
	4 Shrubland	3	16,33
	5 Mosaic herbaceous	2	15,75
	6 Grassland	3	12,83
	7 Paved-Mixed vegetation	5	3,20
	Total	43	
Urban temperature regulation	1 Forest	20	33,50
	2 Mosaic Tree-Shrub	6	17,50
	3 Mosaic Tree-Grass	4	20,00
	4 Shrubland	3	3,50
	5 Mosaic herbaceous	2	7,00
	6 Grassland	3	7,83
	7 Paved-Mixed vegetation	5	8,60
	Total	43	

Annex 3: Research Instruments

Map provided to local ward representatives to identify UGS



Semi-structured Questionnaire to local ward representatives

Introduction

The main objective of this thesis research is to identify the benefits that are provided by green spaces in Taunggyi, and analyse whether they meet the needs of the local residents or not. The studied benefits (or services) are of different typologies: some of them refer to climate regulation or flood risk reduction; while others refer to cultural values as the possibility of walking in a natural environment or enjoying the birds singing in a park.

The aim of this questionnaire is to gather information about the importance that local representatives give to each of the benefits, and also evaluate the specific cultural values provided by each of the selected green spaces.

Section 1: Level of satisfaction and importance of cultural Ecosystem Services for local representatives (Supply & Demand)

1. **Do you visit any green space regularly? Which ones and how often?**

2. **For each service and green space, please answer:**
   a. **What is the importance of the provision of the service by this green space for your personal wellbeing?** (see green space location map in each case)

      Please answer: (1) Very unimportant; (2) Unimportant; (3) Neutral; (4) Important; (5) Very important.

      Here we are talking about subjective wellbeing or happiness: which services do you think contribute most to your personal fulfilment, make you feel peace of mind, and in general make you live well and be happy?

   b. **What is the level of your satisfaction regarding the service supplied by this green space?** Please answer: (1) Very dissatisfied; (2) Dissatisfied; (3) Neutral; (4) Satisfied; (5) Very satisfied.

      With "level of satisfaction" we would like to know if you consider that the service supply by each of the green spaces is enough or if, on the contrary, you think it could be improved (e.g. maybe you think that a green area is not properly conditioned to to go for a walk through it, or to plan school excursions as an educational service).

Cultural Ecosystem Services	G. Space:	G. Space:	G. Space:	G. Space:	G. Space:
RECREATIONAL VALUE (Practising activities as walking, cycling, playing, animal watching, etc.)					
a. Importance for your wellbeing					
b. Supply satisfaction level					

AESTHETIC VALUE (Appreciation of natural beauty, nice smells (as flowers or fruits) or pleasant sounds (as bird singing or wind in the trees))					
a. Importance for your wellbeing					
b. Supply satisfaction level					
SPIRITUAL OR EMBLEMATIC VALUE (Sites important for spiritual or religious reasons; presence of emblematic or sacred species of plants or animals)					
a. Importance for your wellbeing					
b. Supply satisfaction level					
SCIENTIFIC INVESTIGATION / TRADITIONAL ECOLOGICAL KNOWLEDGE (Importance for scientific research and for local practices that maintain traditional knowledge of nature)					
a. Importance for your wellbeing					
b. Supply satisfaction level					
EDUCATION AND TRAINING (Importance to increase understanding of local species and ecosystems through direct observation and experience of nature)					
a. Importance for your wellbeing					
b. Supply satisfaction level					
COMMUNITY BENEFITS (Sites for festivals or community meetings that can promote social cohesion and place attachment)					
a. Importance for your wellbeing					
b. Supply satisfaction level					

3. **Do all members of the community feel the same about this site? Is it likely that different social groups (women/men, young/old, rich/poor, etc.) give different scores to their importance and supply satisfaction level?**

Section 2: Ecosystem Services' importance for local ward representatives

1. **Which is the importance of the Ecosystem Service typologies for your personal wellbeing?**
   Please rate the importance using this range: (1) Very unimportant; (2) Unimportant; (3) Neutral; (4) Important; (5) Very important.

Ecosystem Services typology	Importance
- **Provisioning services**	1 2 3 4 5
- **Regulating services**	1 2 3 4 5
- **Cultural services**	1 2 3 4 5

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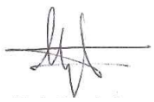
Your Signature(s) : 

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